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AN ANALYSIS OF WIND AND SOLAR ENERGY RESOURCES FOR THE STATE OF KUWAIT

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AN ANALYSIS OF WIND AND SOLAR ENERGY RESOURCES FOR THE STATE OF KUWAIT

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL SUSTAINABILITY

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To Dr. Abdullah Alshuraidah (beloved husband), Nasser Alhusainan (great father), Latifa Alaslawi (amazing mother) and to my brothers and sisters for their endless support, love, and patience during my graduate studies.

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Abstract

Kuwait is an important producer of oil and gas. Its rapid socio-economic growth has been characterized by increasing population, high rates of urbanization, and substantial industrialization, which is transforming it into a large big energy consumer as well. In addition to urbanization, climatic conditions have played an important function in increasing demand for electricity in Kuwait. Electricity for thermal cooling has become essential in the hot desert climate, and its use has developed rapidly along with the economic development, urbanization, and population growth. This study examines the long-term wind and solar resources over the Kuwait to determine the feasibility of these resources as potential sustainable and renewable energy sources.

The ultimate goal of this research is to help identify the potential role of renewable energy in Kuwait. This study will examine the drivers and requirements for the deployment of these energy sources and their possible integration into the electricity generation sector to illustrate how renewable energy can be a suitable resource for power production in Kuwait and to illustrate how they can also be used to provide electricity for the country. For this study, data from sixteen established stations monitored by the meteorological department were analyzed. A solar resource map was developed that identifies the most suitable locations for solar farm development. A range of different relevant variables, including, for example, electric networks, population zones, fuel networks, elevation, water wells, streets, and weather stations, were combined in a geospatial analysis to predict

suitable locations for solar farm development and placement. An analysis of recommendations, future energy targets and strategies for renewable energy policy in Kuwait are then conducted.

This study was put together to identify issues and opportunities related to renewable energy in the region, since renewable energy technologies are still limited in Kuwait because, compared to the cost of conventional electricity in Kuwait, the cost of renewable energy-based electricity is very high. However, the abundant availability of the solar and wind energy as clean renewable energy in Kuwait offers the country significant opportunities to become a leader in the renewable energy sector. In a competition with subsidized oil and gas energy, the success of renewable energy technologies in Kuwait will be subject to the ability of the state to introduce supporting policies, including financial incentives and a regulatory framework to encourage deployment and reduce cost.

Chapter 1

Introduction

Kuwait is currently using and dependent upon fossil fuel for domestic energy use, primarily natural gas to generate electricity. Kuwait has the potential in some geographic locations for the production and placement of wind and solar energies that present an excellent opportunity for policy makers to initiate utility-scale wind and solar resource utilization. Wide installation of renewable energy systems will help Kuwait reduce the country's pollutants, rely less on oil reserves, and protect those resources for generations to come. This renewable source of energy will be reliable and secure and will provide diversity to the Kuwait economy. Kuwait is the fourth largest oil exporter in the world, and most of its economy relies on the revenues from fossil resources. Domestic electricity demand puts a serious burden on the government's budget (Bachelleri, 2012).

From 2003 to 2008, the consumption of both electricity and water increased by 34%. For the last five years, peak demand has grown at an annual rate of 12%, but this has not been matched with adequate new generation capacity, and has resulted in the country experiencing black-outs during summer (Figures 1 and 2; Bachelleri, 2012). The Ministry of Electricity and Water estimates that consumption will increase by 51% for electricity and 65% for water over the next five years (Bachelleri, 2012). Thus, Kuwait, which had a power capacity of approximately 11,600 MW in 2008, will need to double this value by 2020.

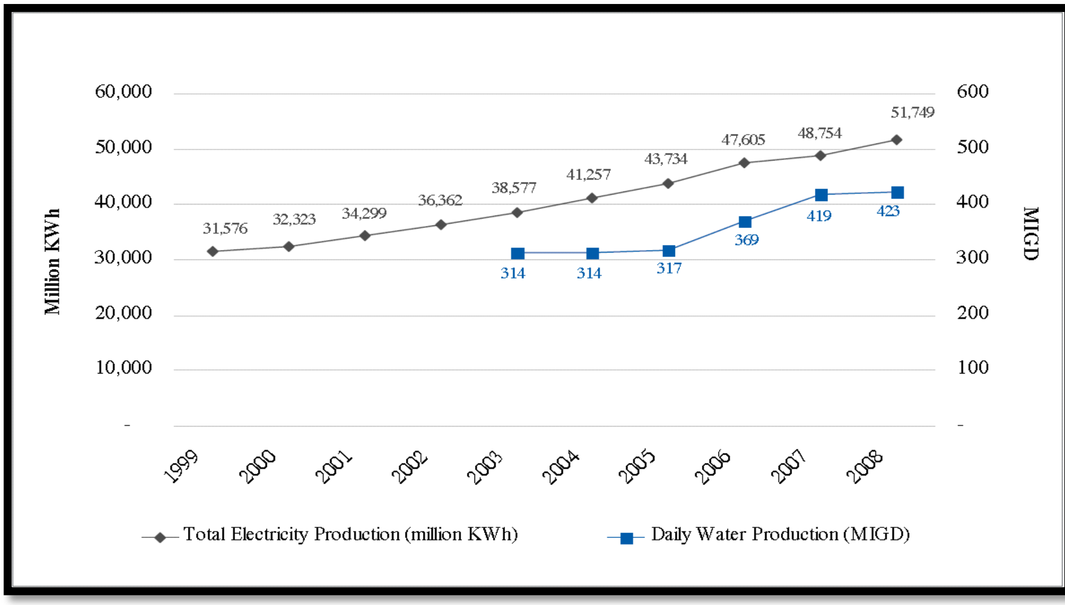


Figure 1 Growth in Electricity and Water Consumption in Kuwait (Bachelleri, 2012)

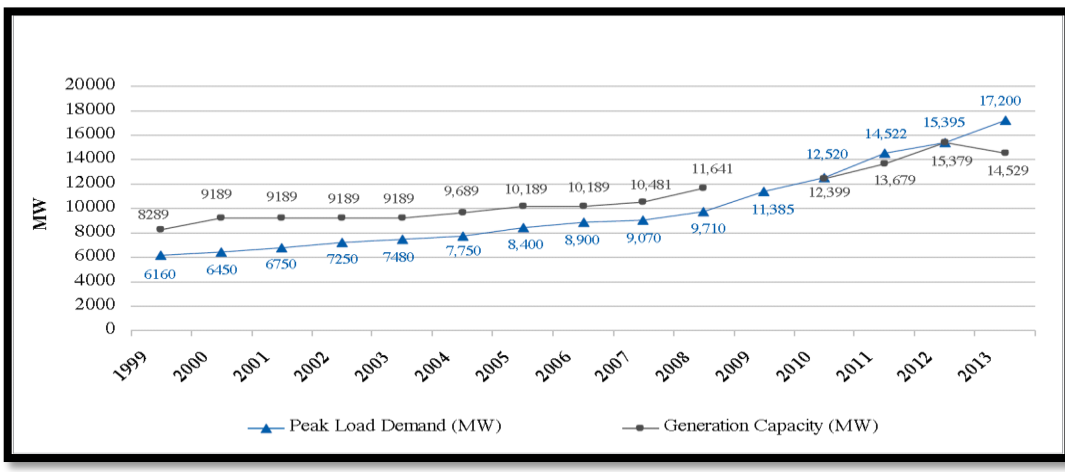


Figure 2 Kuwait Electricity Capacity and Peak Load, 1999 – 2013 (Bachelleri, 2012)

Kuwait has an advantage over other countries in using solar power as its main supply of power, as it has a plentiful supply of the solar resource. In addition, a great advantage is that most of Kuwait is a desert that is scarcely populated, so searching for the ideal location for solar panels should not be environmentally challenging.

Current and Future Electricity Status in Kuwait

When electricity blackouts started in 2006, it was clear that an emergency plan to overcome expected similar crises in the following years was needed. The relevant ministry adopted a new strategy to insure that the electricity and water requirements in the country would be met. This was based upon the strengthening of the productive capacity of electrical plants, and upon a new program, “Tarsheed”, which helped to manage electrical output and demand. However, due to the dramatic increase in demand, Kuwait has no alternative but to research the use of alternative energy from renewable natural resources. The Ministry of Electricity and Water Kuwait now has a strong motivation to devote attention to renewable energy (Ministry of Electricity and Water Kuwait, 2011). The main reason is the necessity to diversify energy sources in the country and not rely on one source until it reaches its depletion (oil and natural gas). The ministry is following closely global developments relating to renewable energy technologies, and is looking into the feasibility and reliability of these new techniques to meet future energy needs in the country (Ministry of Electricity and Water Kuwait, 2011).

Kuwait can begin using renewable energy resources to help ensure abundant electric power for its population without domestically utilizing the vast oil and natural gas resources upon which the Kuwaiti export economy is based. Ali Hajieh, an investigator in the Kuwait Institute for Scientific Research (KISR), has pointed out that 60 percent of the country’s current power output goes to housing electricity, which is the main reason why the country has many blackouts especially in the summer (Middle East North Africa Financial Network (MENAFN), Arab Times-02/25/2009).

Kuwait and the other Gulf Cooperation Council (GCC) countries (Kingdom of Saudi Arabia, Oman, Kingdom of Bahrain, Qatar, United Arab Emirates and Kuwait) depend on natural gas and oil to satisfy their substantial domestic energy requirements (for example, generating electric power, desalting seawater, domestic in-country transportation, and substantial and growing industrial and home needs; AL-Naser and AL-Karaghouli 2000). Most of the GCC are blessed with enormous resources of oil and natural gas. Still, present day fossil fuel resources are finite, and this is motivating the GCC to search for replacement sources for the future.

The sun is one of the future most promising sources of energy because its energy is renewable and clean. The GCC realize the potential of solar energy as a future energy source. Their objectives are to introduce solar technologies, develop systems to satisfy the national needs, and enhance their technical capabilities (Alathel, 1993). The level of solar density in Kuwait and the GCC is among the highest in the world (Figure 3; Table 1). There is considerable scope for developing solar energy resources throughout Kuwait, and solar energy has the potential to provide some electricity to meet all of Kuwait's domestic electricity requirements.

Table 1. Solar radiation in GCC Countries (AlNaser and AlNaser, 2009)

Countries	Global solar radiation (kWh/m^2/day)	Direct Normal solar radiation (kWh/m^2/day)
Bahrain	6.4	6.5
Kuwait	6.2	6.5
Oman	5.1	6.2
Qatar	5.5	5.6
Saudi Arabia	7.0	6.5
United Arab Emirates	6.5	6.0

The advantages of solar and wind power are particularly obvious in the GCC. With average daily sunshine of around nine hours or more as well as low levels of rainfall and cloud cover, the GCC region’s climatic conditions are highly conducive for developing sustainable solar power on a large scale (Figure 3; Katilaine, 2009).

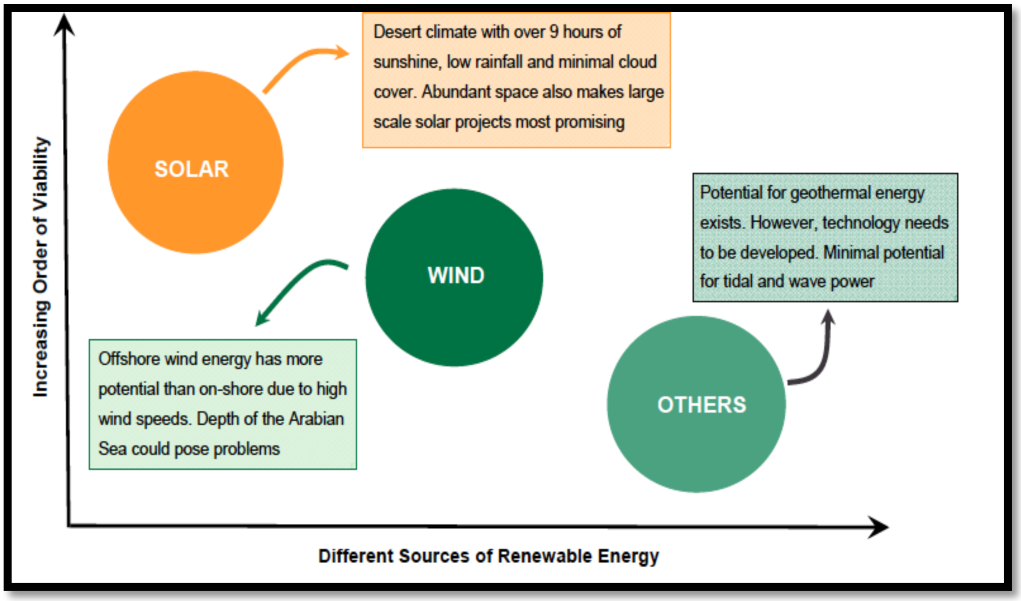


Figure 3. Diagram of potential renewable energy (Katilaine, 2009).

The GCC region also has abundant space to develop large-scale solar energy projects. Large areas of uninhabited desert would enable installations of rows of solar panels, thereby reaping benefits of economies of scale (Katilaine, 2009). Solar plants could also be used to address the energy supply challenges of energy-intensive and costly desalination projects. Large-scale solar power stations could be integrated with desalination plants to create synergies and develop industrial clusters. Some of the initiatives in Masdar City, Abu Dhabi are trying to do precisely this, and the viability of the model will determine the future course of action in using renewable energy for the provision of essential services such as drinking water (Katilaine, 2009).

Masdar City is located in Abu Dhabi, United Arab Emirates. Masdar is a city that is designed to run on green energy (Figure 4). In the sustainable development of the city, the social aspect is designed so as to ensure a harmonious existence of all social categories. The environmental pillar, on the other hand, involves the aspect of proper planning of the city, minimization of wastes, energy conservation, and efficient transport systems (Masdar Capital, 2010).

In the future, renewable energy may eventually become a major source of energy in the GCC as production and utilization costs decrease. The GCC countries have per capita emissions of carbon dioxide (CO_2) that are among the highest in the world (Figures 4 and 5). The GCC region is contributing 2.4% of the global greenhouse gas emissions, and just 0.6% of the global population is living in the GCC (Reiche, 2010). The GCC countries have taken an interest in exploring alternative energy sources and improving the efficiency of energy utilization to help reduce CO_2 emissions.

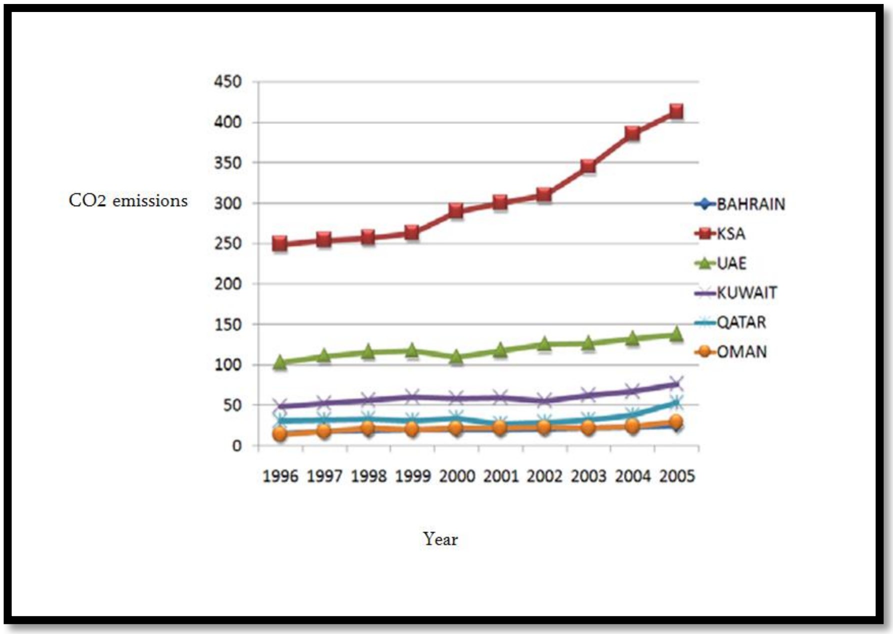


Figure 4. CO_2 total emissions from consumption of fossil fuel for GCC countries (Qader, 2009)

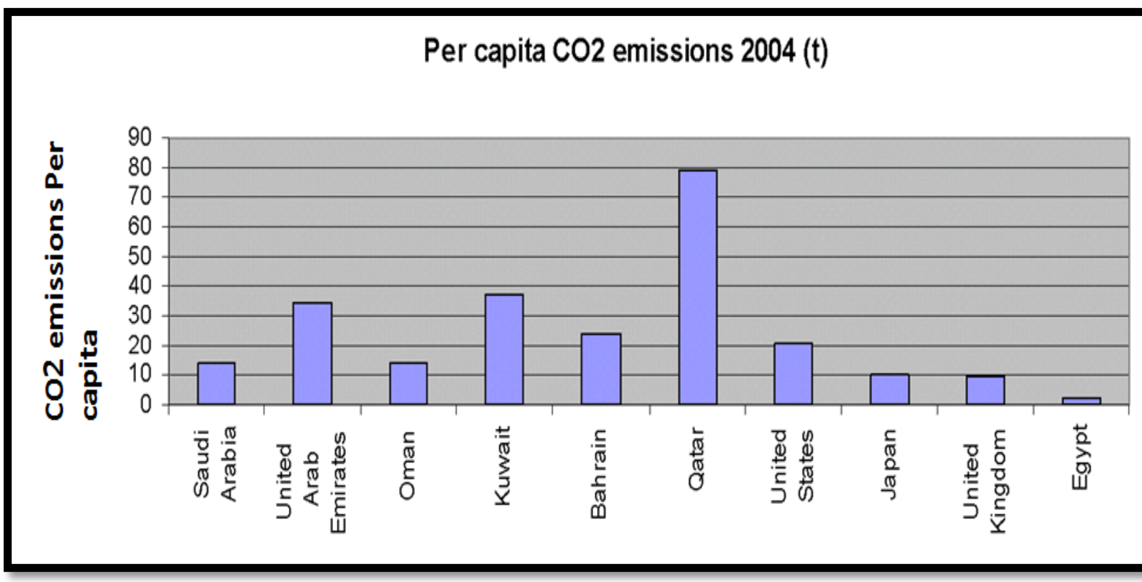


Figure 5. GCC CO_2 emissions for selected countries (Kumetat, 2009)

Development in the renewable energy sector is becoming more and more important to the GCC governments because it is necessary in the long run for the nations, especially considering the prospect of the exhaustion of the fossil-fuel and natural gas resources. GCC electricity is one of the major development challenges in the coming decades and a fundamental dimension of the search for sustainability of the GCC economies (Hertog and Luciani, 2009). The GCC countries have begun to support renewable energy research studies in universities around the world. Most of these studies concern the potential of wind energy, solar energy, and even ocean wave energy. Renewable energy research studies should help to demonstrate the benefits of these renewable resources for future generations and should enhance the economic status of the GCC countries by helping them to establish reliable and resilient green energy systems (Raouf, 2008). Technical support is available within the international community for the assessment of renewable energy based on newer energy-efficient systems. Now is the perfect moment for the expansion of the renewable energy industry in the GCC region (Doukas *et al*., 2006).

Investing in renewable energy in Kuwait

Renewable and energy-efficient technologies can meet a considerable portion of the energy needs of Kuwait. Renewable energy, particularly solar energy, is an abundant resource in the country. It could reach up to 1,672 (million) W/m^2 a year, and holds huge economic promise (Alnatheer, 2005).

Renewable energy has several unique characteristics that should be considered when making comparisons to oil-based alternatives. In the Kuwaiti planning context, these attributes are not currently fully understood. As a result, renewable energy is not appropriately valued, which has led to a situation in which the role of renewable energy technologies in meeting national energy demands is being systemically underrated (Alnatheer, 2005). For oil-exporting countries like Kuwait, shifting to an increased use of renewable and energy-efficient resources increases the potential for expanding the life of domestic oil fields. Since renewable resources do not depend on fuel markets, they are not vulnerable to price rise and fall resulting from changes in international demand. The use of renewable resources also raises economic development, local employment, leads to the creation of jobs using local resources, and to the growth of possible new exports. Renewable technologies, like wind and solar, are modular in nature and require shorter lead time implementation for development than fossil fuel, and can be raised up or down to more closely meet any changes in electricity demand. Renewable resources available in Kuwait can be used to meet, for instance, base load power, peaking power, backup power, remote power, as well as power superiority requirements (Alnatheer, 2005).

In Kuwait, as in most parts of the world, there has been an emphasis on expanding fossil electric supply to keep pace with economic expansion, increased industrial activity, greater urbanization, and improvements in living standards. The development of electricity infrastructure, however, places high demands on investment capital and foreign exchange from oil sales that compete with the financial needs for other pressing national concerns, such as health and education. This constraint on the funds available for electricity infrastructure investment highlights the need for a review of all options to provide electric power for a growing economy and populace.

Geography of Kuwait

Location

Kuwait lies in the northwestern part of the Arabian Gulf, between latitudes 28.30 and 30.06 north, and longitudes 46.30 and 49.00 east (Figure 6). Its north-west borders are with Iraq, and its south and south-west borders are with Saudi Arabia. Its shores of the Arabian Gulf lie on the East (Figure 7). This special location provided Kuwait with a commercial importance., as it is a natural outlet for the northwestern part of the Arab Peninsula. The total area of Kuwait is 17,818 square Kilometers. The population up until June 2007 reached approximately 3,328,136, of which 1,038,598 are Kuwaiti nationals the rest are expatriates and foreigners (Al Diwan Al Amiri Kuwait, 2012).

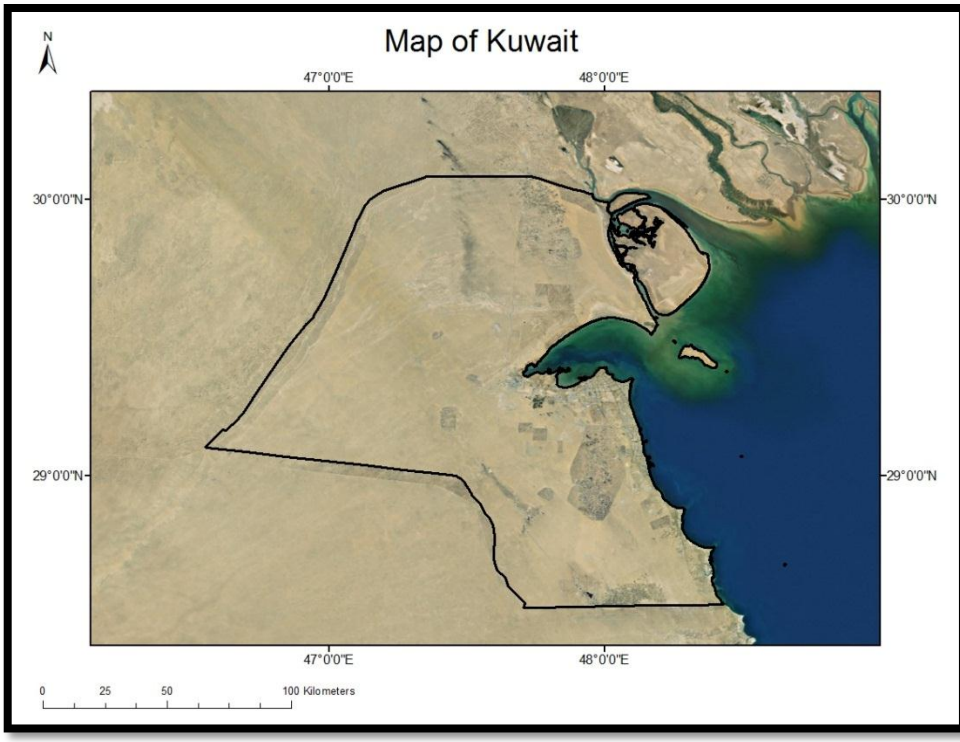


Figure 6. Map of Kuwait

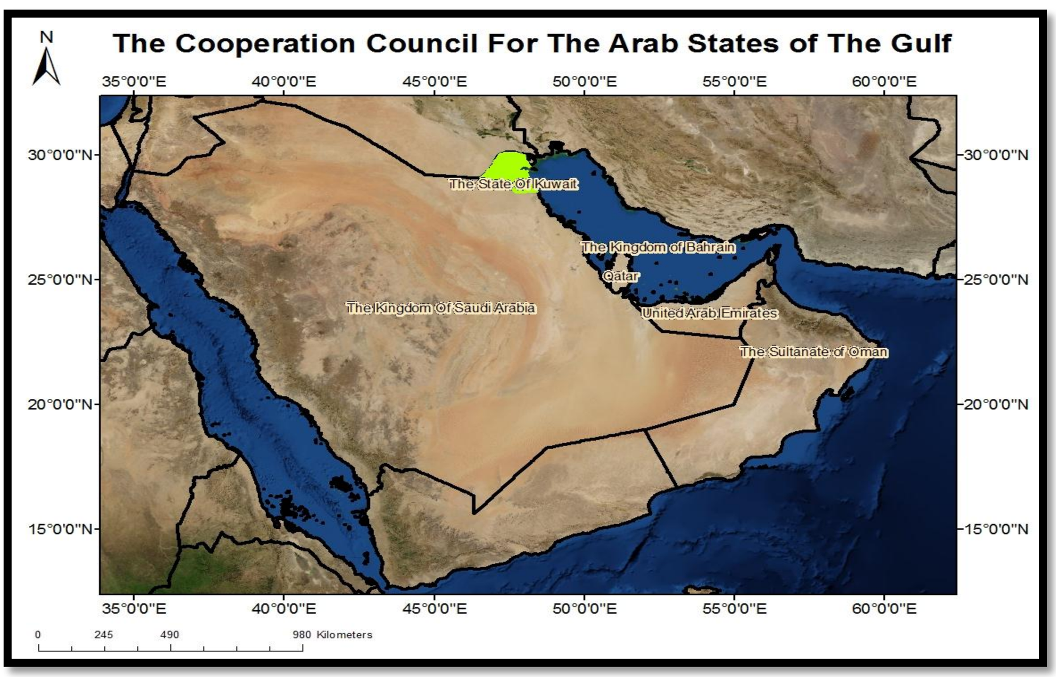
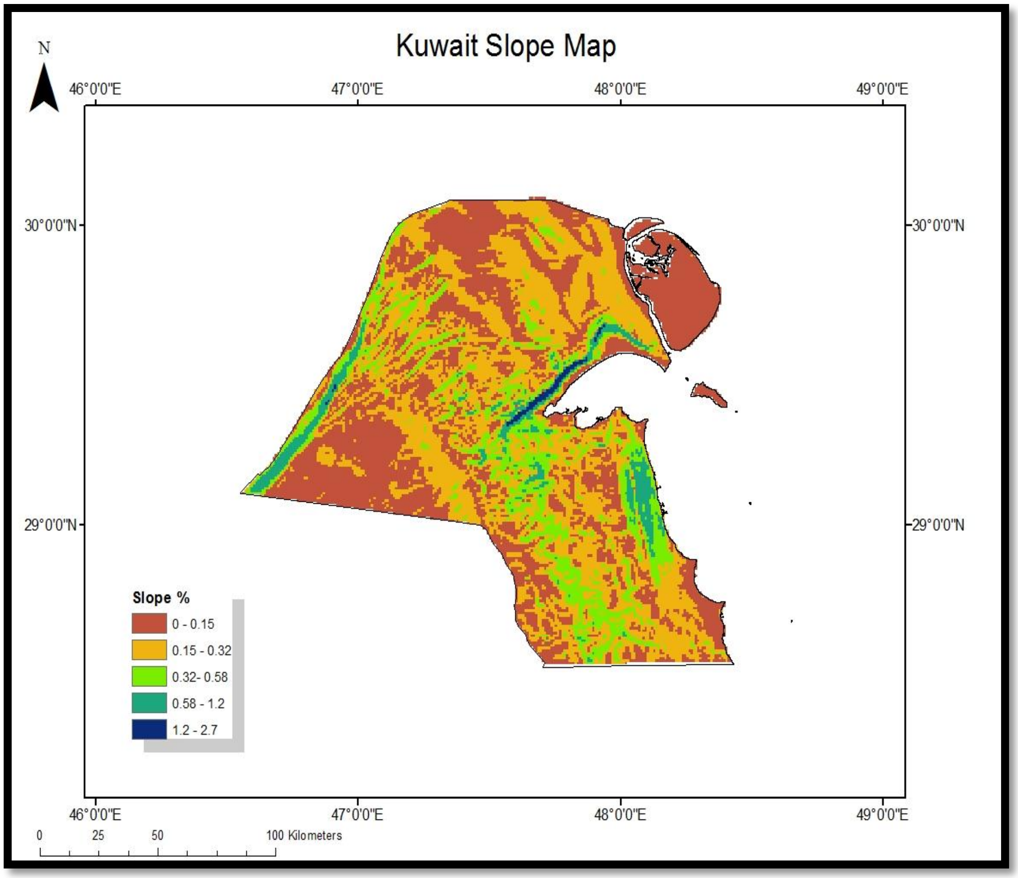


Figure 7. The Gulf Cooperation Council Countries

Topography

Kuwait is famous for its flat topography and slightly uneven desert. The land slopes gradually from sea level in the east at the coast of the Arabian Gulf to the west and the southwest (Figure 8). The height of the southwestern corner reaches 300 meters above sea level. Small hills are spread in Kuwait, such as the ridge of Jal Al-Zour that overlooks the northern coast of Kuwait Bay. The height of this ridge reaches 145 meters. Valley and lowlands, which are locally known as Al-Khubarat, and sand dunes are common in Kuwait. Among the main valleys in Kuwait are Al-Baten Valley and Al-Sheqaq Valley. The first stretches along the western borders of Kuwait, whereas the Al-Sheqaq Valley is located in the northwestern part of Kuwait. The Al-Khubarat Valleys are spread in different places. The most significant of the Al-Khubarat Valleys are Al-Rawdatain and Umm Al-Aish, which are located in the north (Al Diwan Al Amiri Kuwait, 2012).



Figurer 8 Topographic Map of Kuwait

Climate

Kuwait has a continental climate characterized by its dry hot long summer and a short warm winter with occasional rainfall. Rainfall varies from 75 to 150 millimeters (2.95 to 5.91 in) a year across the country; actual rainfall has ranged from 25 millimeters (0.98 in) a year to as much as 325 millimeters (12.8 in). Dust storms often occur during the summer months. The temperature sometimes reaches 50 °C during summer. During winter, the temperature occasionally reaches 18 °C for a high or 0 °C as a low. Winter rainfall is irregular and varies in quantity from one year to another. Autumn and spring seasons are distinguished by their short periods (Kuwait Government Online, 2011).

The dominant wind direction in Kuwait is northwesterly, with winds blowing from this direction approximately 60 percent of the time. Northwestern winds are hot and dry during the summer due to the long distance travelled over the deserts regions of Syria, Jordan and Iraq before reaching Kuwait. Throughout the springtime, the contribution of a southeastern wind rises to compete with that of the dominant northwestern wind. The southeastern winds can become the source of very extreme dust storms in the region, which can reduce visibility to no more than several meters. The dust storms tend to occur during four main periods: from 9 – 12, 17 – 24 June, 1 – 7 and 9 – 17 July when the northwesterly winds intensify during these periods and they reach their peak during the day and then decrease throughout the night (Meteorological Department, State of Kuwait, 1999).

Economy

The economy of Kuwait is a small, relatively open economy; it is mostly controlled by the governmental sector. The state-owned oil industry represents 50% of Gross Domestic Product (GDP), 95% of exports, and 80% of governmental revenues. Crude oil reserve in Kuwait represents 10% of world reserve. Kuwait oil exports include crude oil, oil products, liquefied petroleum gas, chemical fertilizers, salt and chlorine (Kuwait Government Online, 2011). Water resources are very scarce in Kuwait due to the desert nature of the country. Therefore, Kuwait does not have many agricultural lands, which prevents any development of the agricultural sector. In fact, the major part of the production of this sector is fish and cattle. Kuwait depends on several other sectors that play a considerable role in elevating the economy of the country, including the banking and financial sector (Kuwait Government Online, 2011).

The purpose of this research

The aim of this research is to help identify the potential role of renewable energy sources in Kuwait. This study examines the drivers and requirements for the consumption of these energy sources and their possible inclusion within the electricity generation sector. The plan of this dissertation is to develop a technical and economic assessment of solar and wind energy in Kuwait and to develop a renewable energy hybrid system for Kuwait. Also, the development of the *Kuwait Renewable Energy Tool* (KRET) will help stakeholders analyze the wind and solar data over Kuwait to help establish a national energy-planning framework for national energy technology policy in Kuwait. Finally, the most ambitious undertaking of this study is to initiate discussion toward, and suggest one potential strategy for, achieving sustainability and fiscal balance in domestic energy production for Kuwait.

Solar and wind energies are considered as potential energy-resource alternatives largely for the achievement of three main goals: (1) the production of electricity and (2) the reduction of pollution created by operating completely within the traditional energy resources of fossil fuels, and (3) economic sustainability. This research seeks to make use of the available renewable energy resources, mainly solar and wind, to lead to future economic development in Kuwait.

Data and methodology

The data for this study are collected from the Kuwait Meteorological Department and the Kuwait Institute for Scientific Research (Table 2). For this study, sixteen stations monitored by the meteorological department have produced 2 to 13 years worth of hourly and daily wind data and hourly solar data (Figure 9). Each of the meteorological stations of the Kuwait National Meteorological Network is based on a 10m tower and has the following components: five wind speed cup-type sensors at 2, 4, 6, 8 and 10m heights to derive the wind speed profile; one wind direction vane-type sensor at 10m height; one solar radiation sensor (pyranometer) with uncertainty ± 5% (Kuwait National Meteorological Network; Figure 10)

Station Name	Longitude (DD MM SS)	Latitude (DD MM SS)
Mitribah	47 21 35	29 36 35
Jal Aliya	47 34 36	29 36 35
Nuwasib	48 23 21	28 32 32
Abraque Alhbari	46 59 54	29 17 50
Sulaibiya	47 43 17	29 15 35
Managish	47 32 05	29 04 27
Julaia Port	48 17 23	28 51 53
Salmy	46 40 54	29 06 04
Wafra	48 00 29	28 37 01
Ras As-Subiyah	48 05 00	29 34 55
Al-Mutla	47 37 05	29 22 54
KISR	47 54 37	29 20 02
Um Omara	47 06 00	29 07 33
Um Al-Haiman	48 08 22	28 56 35
Al-Taweel	47 52 29	28 55 18
Ras Az-Zoor	48 21 29	28 44 46

Table 2. Elevation and locations of the stations (Data for this table obtained from National Meteorological Network (KISR) and Kuwait Meteorological Department, and Kuwait Meteorological Department.

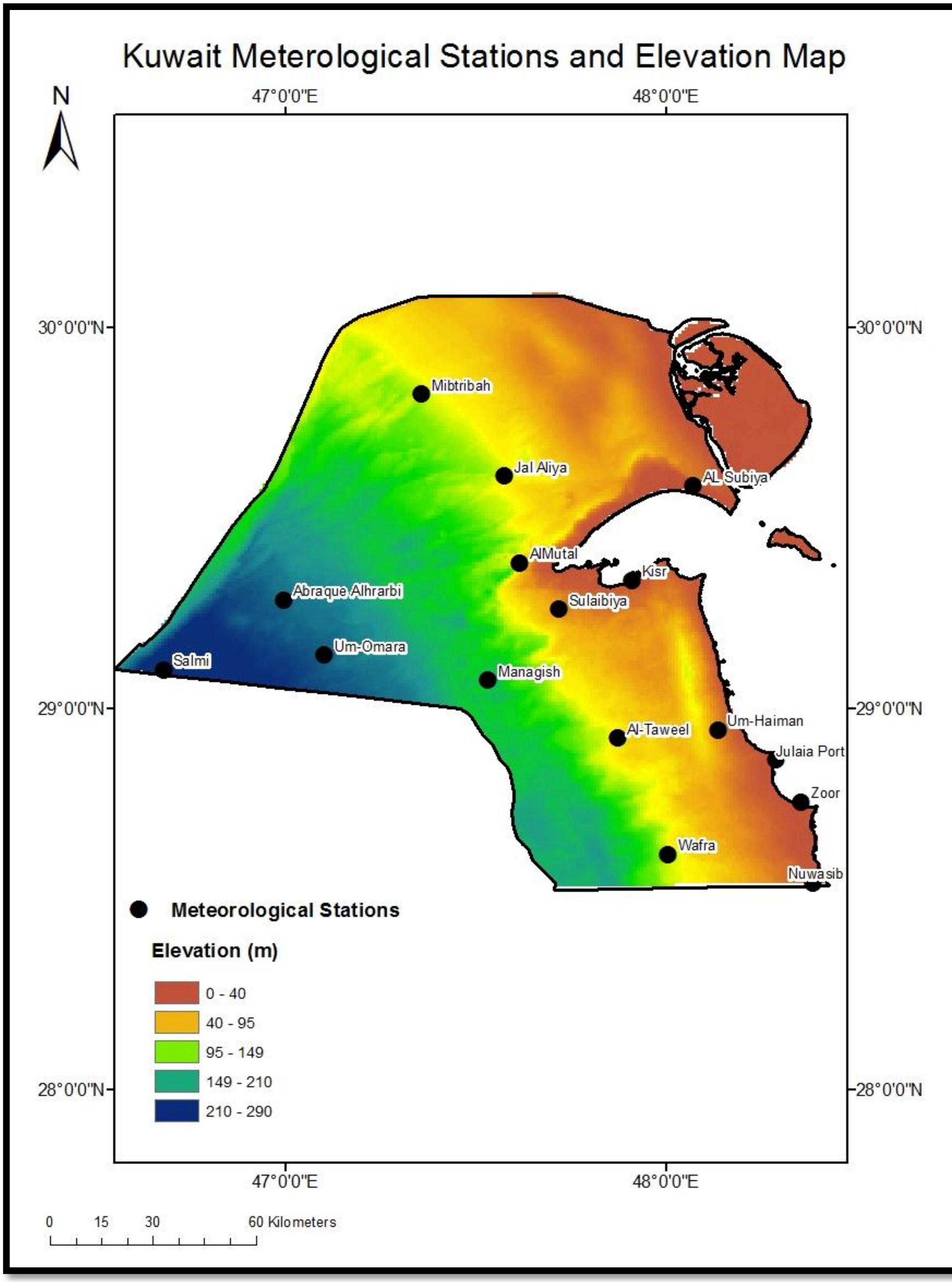


Figure 9. Kuwait Meteorological station locations

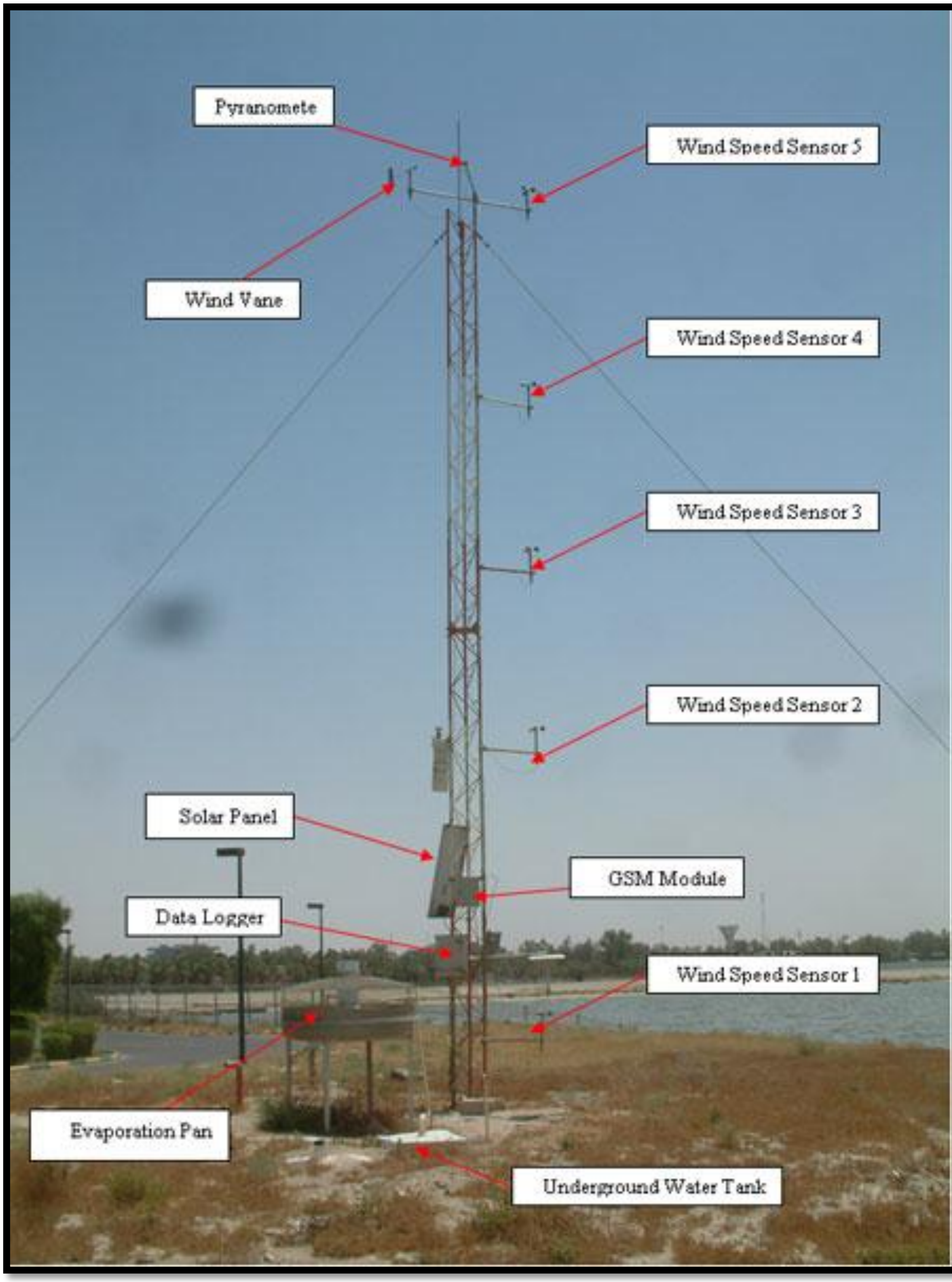


Figure10. A typical meteorological station (KISR) (obtained from Kuwait Meteorological Network)

The adoption of renewable energy in Kuwait

Promotion of renewable energy resources for domestic energy consumption is officially endorsed by the KISR (Kuwait Institute for Scientific Research) in cooperation with the Ministry of Electricity and Water,

> *"The Ministry of the electricity and water for it studies and research techniques of water resources, renewable energy and new 76.887 million dinars (273,279,049 $). Minister said the ministry has developed a comprehensive plan to look at their ability to take advantage and use the latest technology to generate electricity and water, noting that it ended to conduct research required for research of renewable energy and energy conservation and demand management of electricity and water, in addition to water desalination techniques and management request groundwater as well as air-conditioning systems as well as environmental studies. Added that the ministry allocated budget for the current year amount to 10 million dinars for studies and research related to projects that offer by the ministry, useful as contracted with consulting firms worldwide to provide consulting services in the areas of development of the ministry, was hired as the Kuwait Institute for Scientific Research to conduct studies in the field of energy and water." (Alnbaa newspaper, August, 2012)*

The government is currently subsidizing the electrical sector. These subsidies are creating a barrier. Since they are making electricity produced by fuel oil appear to be cheap, they hinder the development of alternative sources of energy, especially renewable energy. The real cost of fuel oil is being masked by the fact that, the government is filling the gap between the cost of electricity produced and the revenues collected from public electricity bills (Alotaibi, 2011).

This study was put together to map out the issues and opportunities related to renewable energy in the region, since renewable energy technologies are still limited in Kuwait because, compared to the cost of conventional electricity in Kuwait, the cost of renewable energy based electricity is very high. This dissertation is organized into 6 chapters: Chapter 1 introduces Kuwait and its potential in renewable energy. Chapter 2 starts with an improved wind energy resource assessment for Kuwait to discuss wind energy potential, and then describes some renewable energy projects in GCC countries, the Middle East and around the globe. Chapter 3 starts with an overview of solar and hybrid analysis and provides a scientific justification for the research methodology, with an estimation of electricity generation capacity and potential and the basics of solar technologies. Chapter 4 begins with the introduction of Kuwait Renewable Energy Tool (KRET), and describes how this tool will help and how it works. Chapter 5 demonstrates a Kuwait National Renewable Energy Plan (KNREP), lists the requirements for successful implementations for KNREP, and provides an overview of renewable energy policy examples around the globe. Chapter 6 provides an overview and summary of the research, as well as recommendations for future developmental strategies.

Chapter 2

An improved wind energy resource assessment for Kuwait

Introduction

Kuwait has significant open land; thus, it may have great potential for utilizing solar and wind energy. Wind and solar may eventually become a major source of energy in the country in the future, as production and utilization costs decrease. Alhusainan (2010) investigated the potential of wind energy in Kuwait and found that the areas around Mutla and Um-Omara are promising. These locations are uninhabited and are not used for cultivation, thus offering superb opportunities for power generation. These prime locations of the country have average 10m wind speeds of 4.3 m/s at Mutla, and 4.4 m/s at Um-Omara.

Material and methods

The research in this chapter is to update the previous study by Alhusainan (2010) by adding two years of data at 10 meters for 9 different weather stations. The research estimates wind power density at 80 meters, which is used to evaluate the wind energy potential at the various stations and provide data useful for selecting optimal locations for situating potential wind farms.

Mathematical analysis

The first goal of this update is to calculate the wind power potential of nine locations. The following mathematical analysis, taken from Ucar and Balo, (2009) was used for wind potential analysis. In Equation (1) below, V_1 is wind speed at height h_1, V_2 is wind speed at height h_2 . For this study h_1 =10 meter and h_2 =80 meter, 80 meters was selected because this is approximately the height of a G.E 1.5 W turbine, and α is the roughness factor. For this study, α was assumed to be 0.03, based upon the work by from Ucar and Balo, (2009).

$$\frac{V_1}{V_2} = \left(\frac{h_1}{h_2}\right)^{\alpha} \qquad (1)$$

The equation was used to estimate wind speed at turbine hub height in the region and to develop the wind resource map.

Wind power density

Wind power density (WPD) is a useful way to evaluate the wind resource available at a potential site. The wind power density, measured in watts per square meter, indicates how much energy is available at the site for conversion by a wind turbine (Maheshawari and Shaban 2006).

The wind power density (WPD) values for Kuwait were calculated by using the following equation:

$$WPD = (\sum 0.5 * \rho * v^3)/n \quad (2)$$

Where ρ = air density, n = number of wind speed observations at 80 meters, and V = wind speed.

Statistical analysis

This study analyzed wind parameters by using 13 years of hourly data recorded at various weather stations in Kuwait. Monthly mean wind speed data from representative stations are presented in Figure 11. The average wind speed for Kuwait is moderate, with an annual average speed of 4-5m/s, and the wind energy in Kuwait is greater in summer than during the rest of the year.

Figure 11 displays observations of monthly wind speed at Sulibiya and Managish (see Figure 9 for specific locations). The June average value for Sulibiya is 6.3 m/s and for Managish is 7.9 m/s. In December, the values are 4.07 m/s for Sulibiya and 5.2 m/s Managish. These areas are located in the windiest part of the country. All zero values were excluded from this analysis because it inclusion will affect the observation of wind energy patterns in the figure. The figure demonstrates that June is the highest month in both areas due to the Summer Shamal wind which is the prevailing northwesterly winds that occurs through the southwest monsoon season but are strongest from early June through mid to late August. The Summer Shamal winds result from a combination of flow around the Pakistani semi-permanent low pressure area, and the Saudi Arabia heat low (U.S. Marine Corps, 1990).

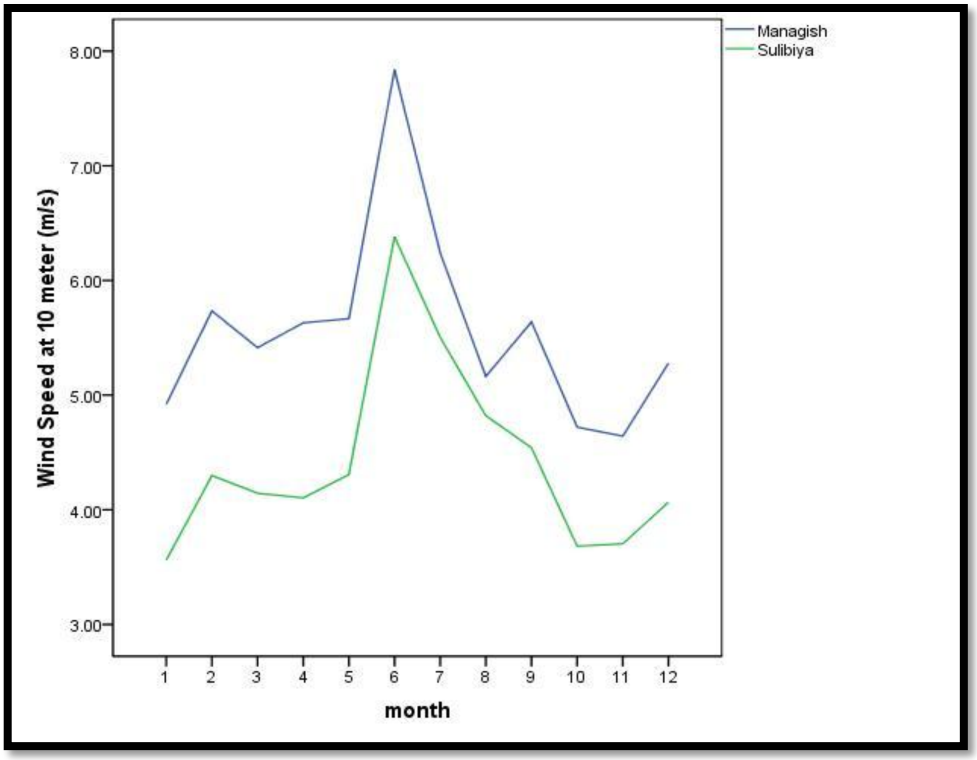
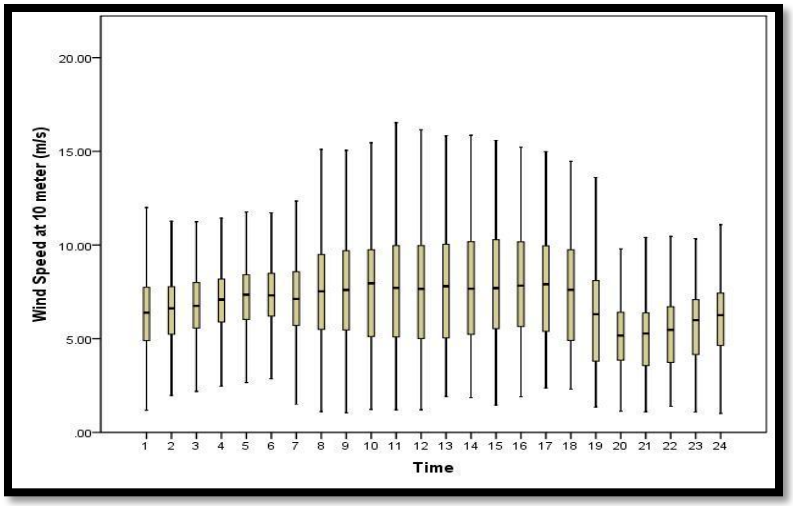
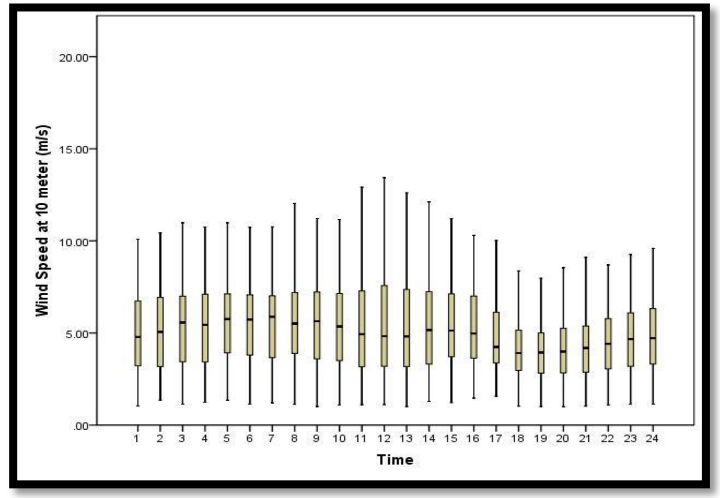


Figure 11. Monthly variation of wind speed at Sulibiya and Managish

The diurnal variability of wind speed during June is much higher than December; the large wind power supply in summer coincides with a large demand for electricity in the country. Figures 12 and 13 represent the diurnal variability of wind speed at Mutla for the month of June and December from 1998-2010. The diurnal variability of wind speed at Mutla in June shows a highest average 7.9 m/s at 16:00 and the lowest average of 5.1 m/s at 21:00. The month of June has the most active wind, which would help produce electricity when it is most needed.





Figures 12 and 13 Diurnal pattern in June and December at Mutla respectively

The wind speed starts to increase in the afternoon and reaches its peak at 15:00 and starts to decrease to reach its lowest point at 22:00. In contrast with the month of December, the highest average 5.6 m/s at 6:00 and the lowest average 4.1 m/s at 19:00. Winds along the north shore are northwesterly to easterly during the night and early morning and southerly to westerly during late morning and afternoon.

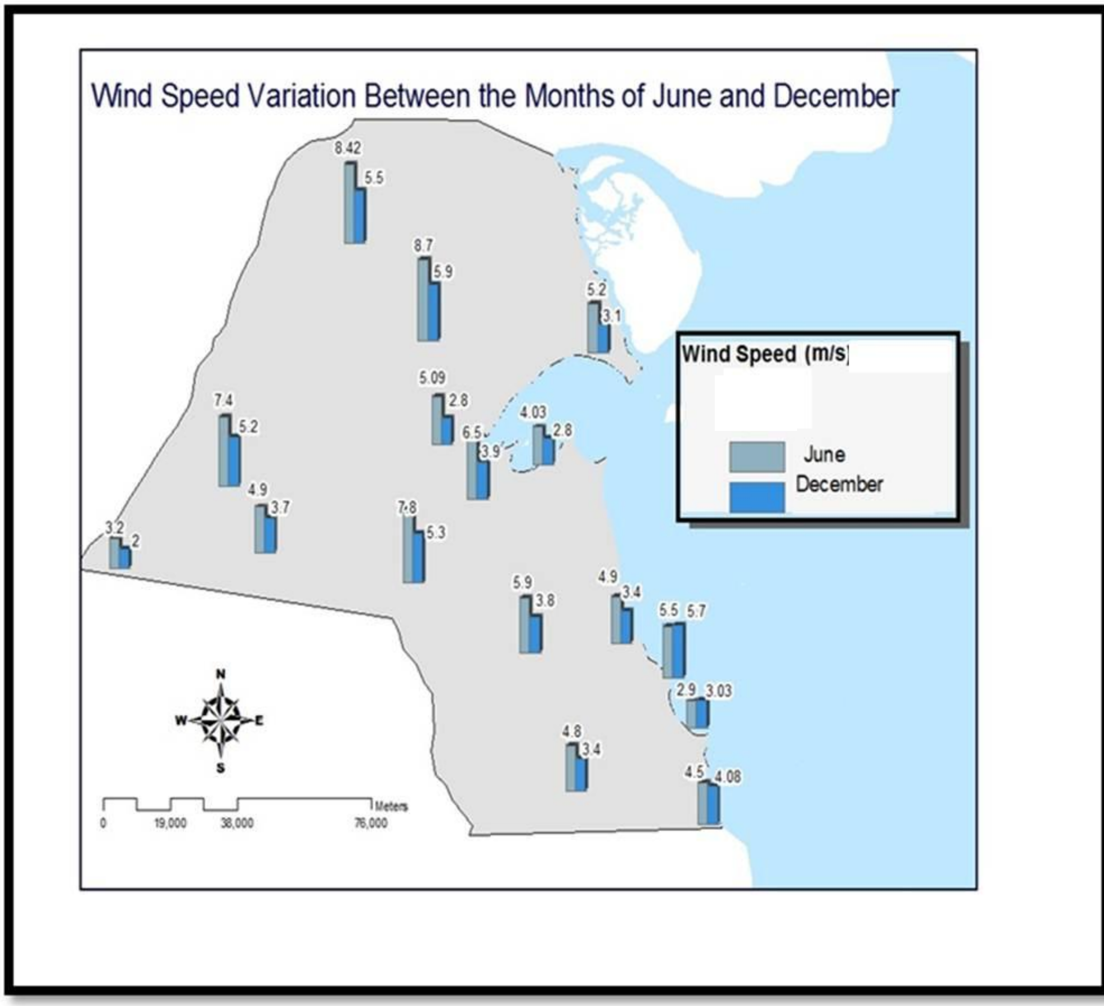


Figure14 Average wind speed during June and December

Figure 14 shows the spatial pattern of wind speed during June and December, and the values indicate that the month of June is windier than December in almost all the stations. Stations along the coastline show the same or similar values for both months because of the sea breeze, which that affects the measured wind speed during all months. The figure demonstrates wind speeds increase to reflect the development of strong some continental thermal lows inland. In the Summer months they increase due to the Shamal winds.

Wind power density is a useful way to evaluate the wind resource available at a potential site. The wind power density, measured in watts per square meter, indicates how much energy is available at the site for conversion by a wind turbine. Yearly hourly mean wind power density was calculated to establish yearly patterns of wind power density. Yearly wind power density varies from one station to the other and also year to year (Figure 15).

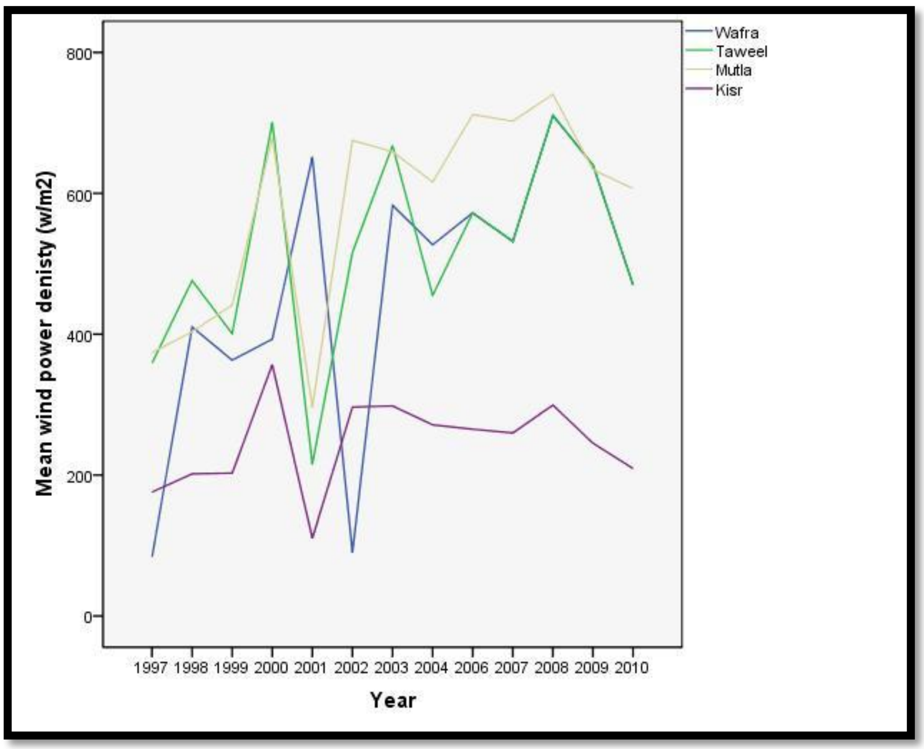


Figure 15 Yearly hourly mean wind power density at 80 meter.

The variation indicates that wind speed is location-dependent. For some of the best examples, consider Mutla which is *not* an urban area; and Al-Taweel which is located in the biggest oil field in the country; Wafra which is the region of the country where Kuwaiti people owns farms; and the KISR station, situated in the highly populated urban area in the east of the country. The highest yearly mean value is 741 w/m^2 in 2007 and in 1997 the lowest yearly mean value is 84 w/m^2.

Note that the variations of wind power density at the Taweel station from 1998-2010. In 2008, the yearly mean value is 711 w/m^2 and in 2001 the lowest yearly mean value is 215.62 w/m^2. The figure displays the variation of wind power density at the KISR station from 1998-2010. In 2000 the yearly mean value is 357 w/m^2 and in 2001 the yearly mean value is 109 w/m^2.

Viable locations for utilization of wind power and optimal locations for potential wind farms and wind power curve

Developing a wind resource map, and creating a spatial pattern requires interpolating values between stations. The selection of the stations is based upon wind power density (WPD) and the location of these stations within the WPD classes. WPD classes range from 1 to 5, and classes 3-5 are typically considered economically viable. .

Figure 16 represents the updated data from 1996 to 2010. Wind conditions in all parts of the country at 80 meters indicate strong wind speeds in the north-western part of the country. This map could be helpful to interested wind farm developers who could use this to site stations to obtain the exact estimate of potential wind energy production. For hourly stations, Mutla and Um-Omara are locations with great promise for the utilization of wind energy. These locations have high median wind speeds of 4.4 m/s at a height of 10 meters, which correspond to an estimated 5.9 m/s at a height of 80 meters. Note, however that the optimal location selection ideally needs a peak hourly data to be complete. In fact, if the hourly data were available for all the weather stations these two will be selected as optimal locations to build wind farms since the wind energy is found to be highest at the Northern desert part of the country.

Thematic data were also included to examine the impact of variables such as electric networks, population zones, and fuel networks. Elevation, water wells, streets, and weather stations were also combined in a geospatial analysis to predict suitable locations for wind farm development and placement. The exclusion zone is a restricted unsuitable zone for wind turbine installation. Exclusion zones are comprised either of protected environmental areas, oil fields, or army bases. The zone has been excluded in order to protect its effects on environment, economic status, and politics. The wind map attempts to identify the most and the least suitable potential areas for utilizing wind energy.

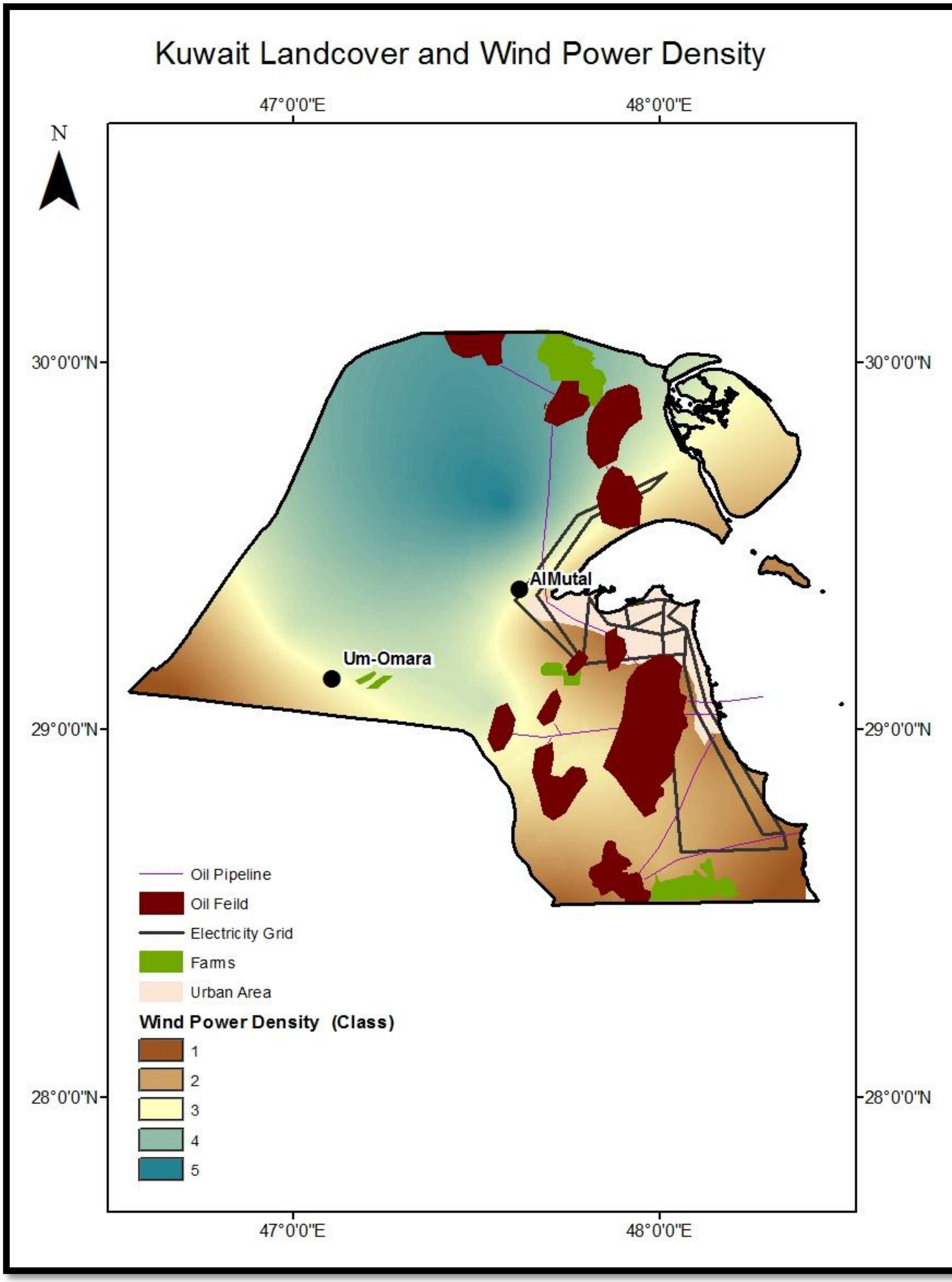


Figure 16 Wind resource map with land use patterns

The wind power curve describes how much power a particular wind turbine can extract from the wind at a variety of different wind speeds. The GE 1.5 MW turbine power curve (Figure 17) represents the electric power produced by an individual wind turbine at different wind speeds. By using the GE1.5 turbine power output value for wind at 80 meters, electricity production can be estimated. Power was estimated at Mutla from 1997 to 2010 and Um-Omara from 2004 to 2010. Note that any wind speed value lower than 3 m/s or more than 25 m/s will produce no electricity.

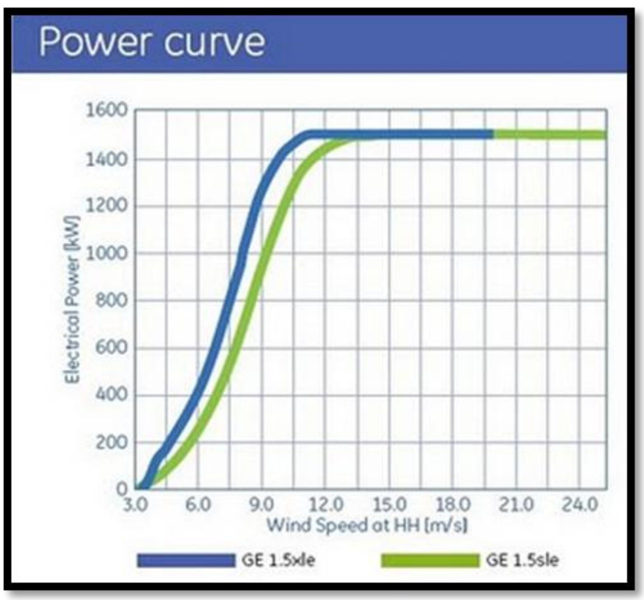


Figure 17 GE 1.5 Power Curve (obtained from gepower.com)

The dollar amount of energy produced by wind power was calculated according to the GE 1.5 MW power curve value and the estimated cost of electricity in Kuwait; the value is calculated at 0.002 Kuwaiti Dinars (KD), 0.007$ for kWh, for residential electricity.

Thus, using the GE 1.5MW turbine power curve model is it estimated that a single turbine could produce 471,360,591 kWh at Mutal from 1998-2010 and 698,598,213 kWh at Um-Omara from 2004-2010. Using current cost estimates, the cost of wind electricity generation would be 469,683 $ for Mutla and 456,751 $ for Um-Omara.

Now that the wind patterns and energy have been analyzed, the study will focus on Solar energy. First there will a review of the literature, followed by a data description and analysis, and then a summary of the optimal solar locations.

Review of Solar Energy Literature

Solar energy has been used for thousands of years. Currently, harnessing the sun‘s energy includes a diverse set of technologies that range from simple sun drying of crops to direct generation of electricity using photovoltaic cells. Solar energy technologies can be divided into two groups: solar thermal applications that convert solar radiation to thermal energy, which can be directly used or converted further into electricity, and applications that directly generate electricity from sunlight using the photovoltaic effect (Byrne et al., 2010).

Renewable, sustainable, and clean solar energy resources are much larger than the world’s energy demand (Sen, 2008). Solar radiation at the top of the atmosphere is known as the terrestrial solar constant of about 1367 W/ m^2. The total annual downward solar energy at the surface is about 3.3 X 10^{24} J, or 6800 times more than the world annual energy consumption (Sen, 2008). Even by excluding the water surface and assuming a solar energy conversion efficiency of 10%, the usage of solar energy over 0.5% of the land surface could meet the current global energy demand. Solar energy is expected to play a very significant role in the future especially in developing countries, but it also has potential in developed countries. Figure 18 demonstrates the annual global mean downward solar radiation distribution at the surface (Liu et al., 2009).

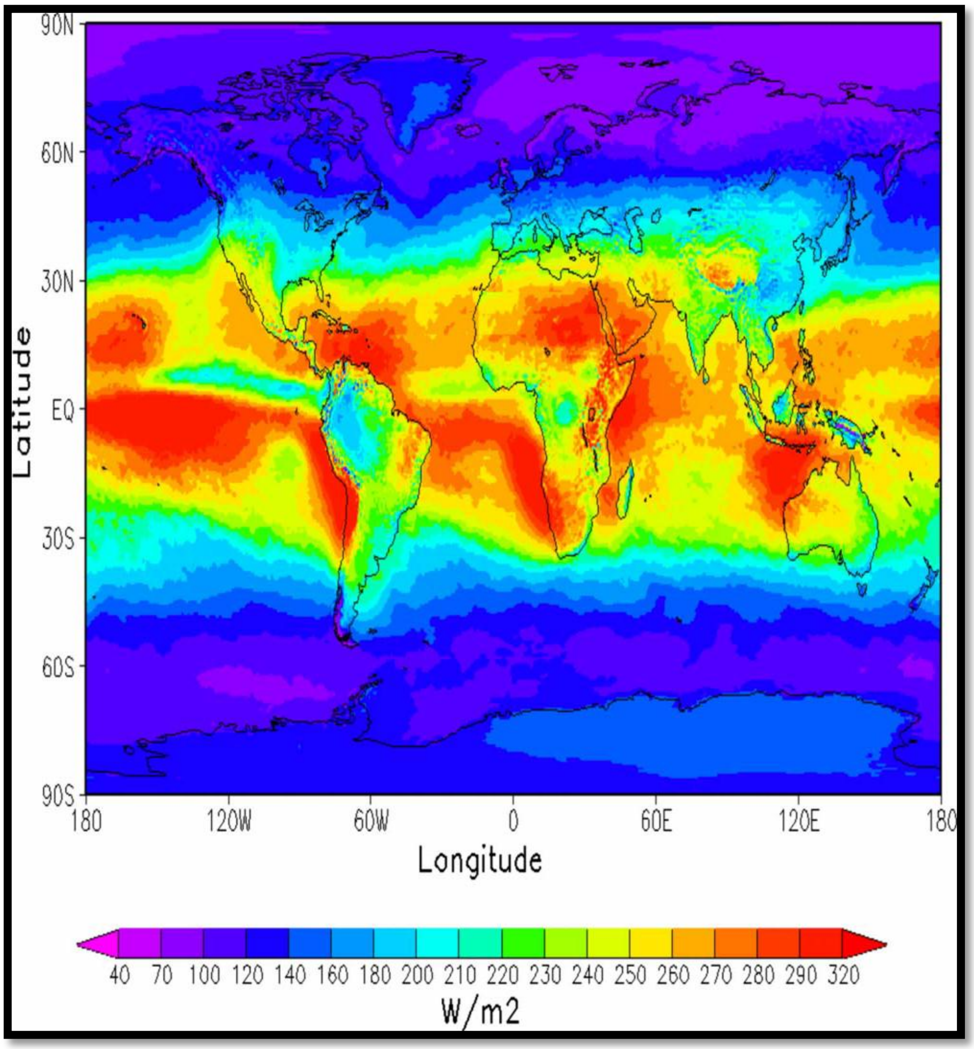


Figure 18 Annual global mean downward solar radiation distributions at the surface (Liu et. al, 2009).

Solar electric or photovoltaic systems (PV), which convert sunlight directly into electricity, are attractive as an energy technology. PV modules do not release gaseous or liquids pollution, need no fuel and are easy to maintain.

PV systems are used primary in rural areas to provide power for lighting, water pumping, and many other applications in both individual household and at the community level. The factor that converts the sun light into electrical energy directly is called a solar cell or photovoltaic cell. PV cells are used to provide electrical power for range of applications (Boxwell, 2012). Concentrated solar power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam (Figure 19, 20). PV is expanding very rapidly due to effective supporting policies and recent dramatic cost reductions. PV is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions (Boyle, 2004).

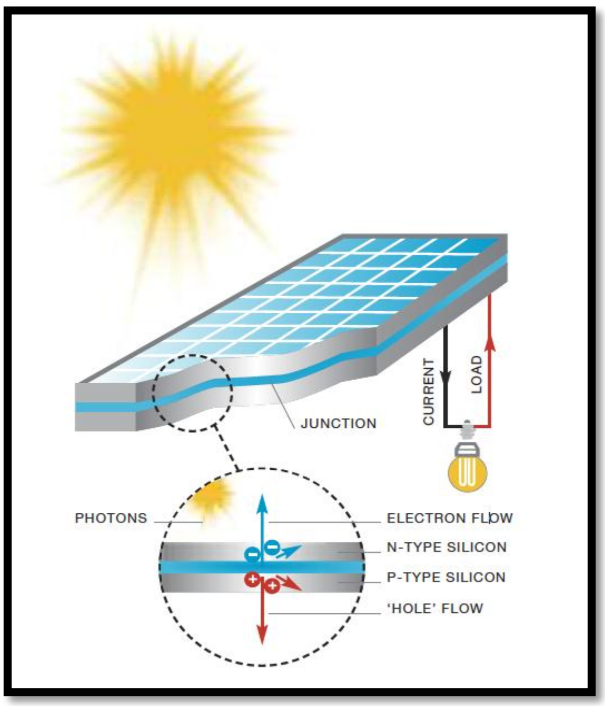
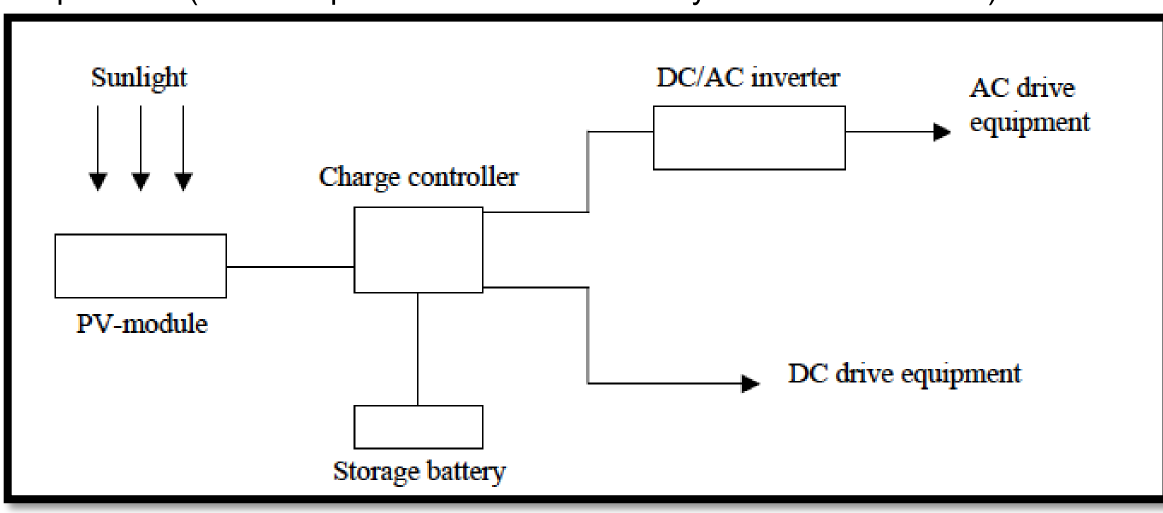


Figure 19 Example of the Photovoltaic solar system (obtained from The European Photovoltaic Industry Association 2011).

Solar cells produce direct current (DC) power, which fluctuates with the intensity of the irradiated light. This usually requires conversion to certain desired voltages or alternating current (AC), which requires the use of inverters.

Multiple solar cells are connected inside the modules. Modules are wired together to form arrays, and then tied to an inverter, which produces power with the desired voltage and frequency/phase when it's AC (Figure 20; The European Photovoltaic Industry Association 2011). Photovoltaic systems contain cells that convert sunlight into electricity. Inside each cell there are layers of a semi-conducting material. Light falling on the cell creates an electric field across the layers, causing electricity to flow. The intensity of the light determines the amount of electrical power each cell generates. A photovoltaic system does not need bright sunlight in order to operate. It can also generate electricity on cloudy and rainy days from reflected sunlight (International Energy Agency, 2010 a).

Figure 20 The system of photovoltaic energy consists of the components (The European Photovoltaic Industry Association 2011 a)



Several cells are usually connected in a unit in series or in parallel for practical use. Cells connected in such a manner are called a module. To obtain much a larger quantity of electricity, a numbers of modules are connected together to form a panel. A group of panels combined together called an array, then used as an electric power stations for PV energy systems (Wengenmayr,and Buhrke, 2008).

After a certain threshold, solar panels will generate less power when exposed to high temperatures compared. Solar PV systems can often generate more electricity on a day with a cool wind and a hazy sun then when the sun is blazing and the temperature is high. As solar panels are exposed to the sun, they heat up, mainly due to the infrared radiation they are absorbing (Boxwell, 2012). The sun light is radiated on the surface of the fixed collector at various angles during the day, and because of the light reflection from the surface of the collector, full absorption is not possible. This becomes important in the photovoltaic converters due to the expensive solar modules (Moghbelli and Vartanian,2006).

The voltage is highly dependent on the temperature, and an increase in temperature will decrease the voltage. Figure 21 shows the effect of temperature on the I-V (current-voltage) characteristic of PV module at constant radiation. With decreasing temperature, PV current decreases slightly, but PV voltage increases clearly. As Figure 22 indicates, output power of a photovoltaic module increases with decreasing temperature (Fesharaki et al, 2011).

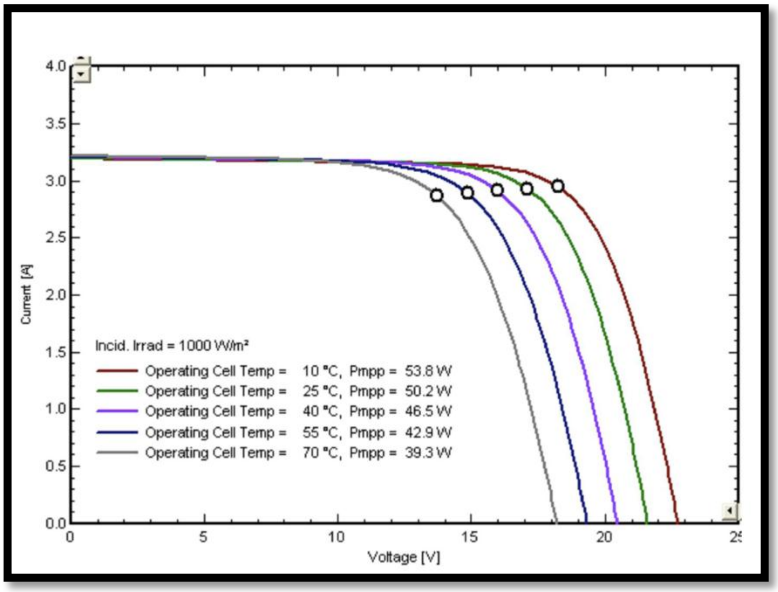


Figure 21 Output I-V characteristics of the PV module at constant radiation (Fesharaki et al, 2011).

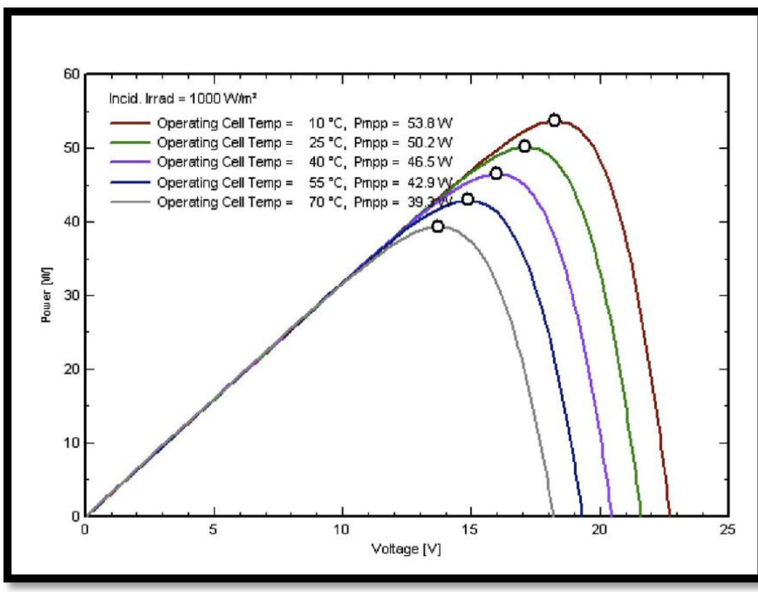


Figure 22 Output P-V characteristics of the PV module with different temperatures (Fesharaki et al, 2011).

Concentrated solar power (CSP)

CSP uses the renewable solar resource to generate electricity while producing very low levels of greenhouse-gas emissions (Figure 23, 24). Unlike solar photovoltaic (PV) technologies, CSP has an inherent capacity to store heat energy for short periods of time for later conversion to electricity. CSP plants can continue to produce electricity even when clouds block the sun or after sundown. CSP plants can also be equipped with backup power from combustible fuels. CSP technologies therefore benefit from advances in solar concentrator and thermal storage technologies (International Energy Agency, 2010 b).

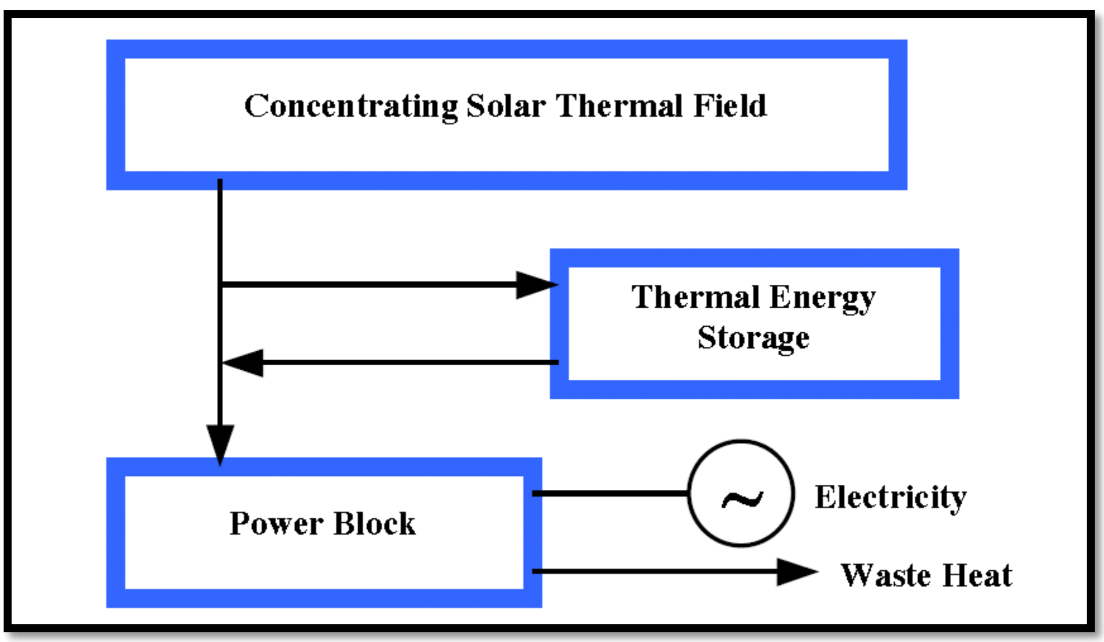


Figure 23. Components of a Concentrating Solar Power system (Korthapalli and Greska).

Figure 24. The PS10 solar power plant concentrates sunlight from a field of heliostats onto a central solar power tower. Concentrated solar power could be one renewable energy option to emerge as a viable large-scale alternative to coal-fired electricity (obtained from power-technology.com)

Solar cell efficiency

The efficiency of a solar cell is a measure of how well a solar cell can convert the light of sun into energy. If all the light energy falling is converted into electricity, its efficiency will be 100% (Table 3; Ardani and Margolis, 2011). In 2010, the typical efficiency of crystalline silicon-based PV commercial modules ranged from 14% for multicrystalline modules to 19.3% for the highest-efficiency monocrystalline modules (average monocrystalline module efficiency was 14%). For thin-film modules, typical efficiencies ranged from 7% for a-Si modules to about 11% for CIGS and CdTe modules (Ardani and Margolis, 2011).

Table 3. 2010 Commercial Module Efficiency (Ardani and Margolis, 2011).

Technology	Commercial Module Efficiency
Monocrystalline silicon	14%
Multicrystalline silicon	14%
CdTe	11%
a-Si	6%
CIGS	11%
Low-concentration CPV with 20%-efficient silicon cells	15%
High-concentration CPV with 38%-efficient III-V multi-junction cells	29%

Solar related projects in Gulf Cooperation Countries (GCC) and Middle East

The GCC is rich in renewable energy resources with high values in daily solar radiation. The objective here is not to provide exact country data on these resources but to show ongoing research work on the assessment of renewable resources and its potential use in electricity generation. The GCC countries have recently adopted a more pro-active approach to addressing environmental issues and benefits of renewable energy (Table 4 a, b), as seen in projects such as Masder City, which is a regional model for renewable energy use and energy efficiency. Not all Arabian countries have taken an active part in exploring renewable energy, but the Kingdom of Bahrain and the United Arab Emirates and recently Qatar and Saudi Arabia are among the Gulf region's leading countries in renewable energy projects (Reiche 2009).

Table 4a. Environmental impacts of solar and wind energy (Wise and Yang, 2012).

Renewable Energy Type	Environmental Advantages	Environmental disadvantages
Solar	Solar energy is renewable.	CIS or CdTe modules because the cells it contain the substance there is small chance to fire the array and might cause small amounts of chemicals to be released to the environment.
	Helps in reducing toxic gas emissions (GH emissions).	Pollution can be a disadvantage to solar panels, as pollution can degrade the efficiency of photovoltaic cells. Clouds also provide the same effect, as they can reduce the energy of the sun's rays. This certain disadvantage is more of an issue with older solar components, as newer designs integrate technologies to overcome the worst of these effects.
	Provision for collection of batteries and facilities to recycle batteries are necessary	
	Emit no gaseous or liquid and no radioactive substance	
	They emit no noise	
	PV cells are made of silicon and it's not intrinsically harmful	
	Most of PV manufacturing they recycle the already used PV.	

Table 4b. Environmental impacts of solar and wind energy Wise and Yang, 2012).

Renewable Energy Type	Environmental Advantages	Environmental disadvantages
Wind	Does not cause greenhouse gases or other pollutants.	When wind turbines are being manufactured some pollution is produced. Therefore wind power does produce some pollution
	Zero air, water and solid waste emissions.	Bird and bat collision fatalities, Bird and bat fatalities through collisions with wind turbines are among the most publicized environmental concerns associated with wind power plants
	Total fuel-cycle emissions, including emissions experienced during construction, fuel extraction (zero for wind) and operating cycles, are very low compared with all fossil fuels and many other types of generating technologies.	Populations of many species of birds and bats are in decline, leading to concerns about the effects of wind energy on vulnerable species
	There no need for destructive resource mining or fuel transportation to a processing facility	Visual impacts, and specifically how wind turbines and related infrastructures fi t into the surrounding landscape, are often among the top concerns of communities considering wind power plants.
	Supply power to rural areas	The impact on wildlife is likely low compared to other forms of human and industrial activity
	They emit no noise	Construction, wind systems can engage the transportation of large and heavy equipment. This can cause a large temporarily disturbed area near the turbines. Erosion is an additional possible environmental problem that can stem from construction projects. The single most reliable technique for limiting erosion is to avoid grading roads and to perform site reclamation post construction

Kingdom of Saudi Arabia (KSA)

According to AlNaser and AlNaser (2009) the Kingdom of Saudi Arabia (KSA) formed a program with the United State of America in 1977 (SOLERAS, Solar Energy Research-American/Saudi) to address solar energy and economical related issues. The Solar Electric Stirling Engine Concentrator Solar Thermal Dish Project was another program joint between Saudi Arabia and Germany in 1982, and it was then expanded to include sizable projects dedicated to the advancement of solar hydrogen technologies. This program was aimed at the production of 50 kW of electrical power from each thermal dish. It involved the development, construction, and testing of two 17 m diameter large-scale membrane solar concentrators (AlNaser and AlNaser, 2009).

Another project established in Saudi Arabia is the Solar Village project, located near the villages of Al Jubailah, Al Uyaynah, and Al Higera, which are about 50 km northwest of Riyadh. The objective of this project is to use solar energy to provide power to remote villages not served by the electric power grid. The project was designed during the late seventies and started operation in the early eighties. The entire photovoltaic (PV) project site occupies an area of approximately 67,180 m^2. This computerized 350 kW concentrator PV electricity-generating power station includes 160 PV arrays, with a total peak output of 350 kW (Alawaji, 2001).

Kuwait

In Kuwait, research projects have been conducted at the Kuwait Institute for Scientific Research (KISR) since 1975 totaling around $ 50 million. The following are some examples of the solar energy use in small scale:

- “Thermal and electricity application projects Kuwait English School Salwa, operated 1984:

    - Daily electricity load; 80 kWh.
    - 630 PV modules; No. of batteries 110.
    - Max electricity production capacity: 24.2 kW.
    - Batteries storage capacity: 200 kWh.
    - Voltage: 220 V. • Operated 1984.

- KISR’s Solar House (application laboratory) operated 1984:

    - Daily electricity load: 2.5 kWh
    - 76 PV modules; 48 batteries.
    - Max electricity production capacity: 2.6 kW.
    - Batteries storage capacity: 34 kWh.
    - Voltage: 48 V..”(AlNaser and AlNaser 2009, page 8)

Oman

In Oman, the Renewable Energy installed is 235 kW, among different projects:

- “Oman Solar System (OSS) has already designed, manufactured, and installed solar lighting systems: • Interior roads, • Public toilets,
- Solar power supply systems for unmanned microwave telecommunications systems to Omantel,• pay phone booths, • TV transposer systems MOI, • Variety of systems for oil and gas industry in Oman.
- The solar systems for TV transposer stations have been installed at mountain top with access to the sites by helicopters.
- Oman Solar System (OSS) has also recently completed a project for design, manufacturing, installation, testing, and commissioning of solar photovoltaic power systems for

Petroleum Development Oman PDO for powering 12 radios base stations at interior operation sites.

- Solar Power Systems for ten seismic monitoring stations spread all over Oman. OSS in collaboration with Kinemetrics Inc. USA had made this project.
- Oman's first wind-powered, electric water pumping system at a remote site around 900 km south of Muscat. This project is irrigation and for research purposes by The Ministry of Water Resources MWR, this system was installed by OSS."(AlNaser and AlNaser 2009,page 11)

Al-Badi et al. (2011) investigated the economic prospects of using solar PV electricity in Oman. Using average daily global solar radiation and sunshine duration data, the study assumed a solar PV power plant at 5-MW at each of 25 locations to calculate the capacity factor, the levelized cost of electricity (LCOE) per kWh of electricity produced, and potential emission reduction due to the PV system (Al-Badi et al., 2011).

Gastli and Charabi (2010) developed solar radiation maps to demonstrate and highlight the geographical distribution of solar radiation covering the AlBatinah region in Oman. These maps help to select the optimum sites for solar farms. Gastli and Charabi (2010) aimed to develop the first micro-scale geographical mapping models to locate the most suitable PV sites. They used a multi-criteria analysis for solar energy purposes, including a set of geographically defined criteria, such as solar radiation, elevation, residential area, sensitive area, transmission lines, load demand, and road accessibility (Gastli and Charabi, 2010).

Another analysis for solar energy in Oman showed that a significant portion of the land demonstrates high suitability. It was found that Concentrator Photovoltaics (CPV) technology provides very high technical potential for implementing large solar plants. In fact, if all highly suitable land is completely exploited for CPV implementation, it could produce almost 24.5 times the present total power demand in Oman. Developing reliable analysis for this region in Oman will significantly help the planning of new transmission lines, attract more solar project developers to build solar PV generation facilities, and produce clean and reliable electric power in the country to meet growing energy need (Gastli and Charabi, 2010).

In conclusion Gastli et al. (2010) found that that the quantity of solar radiation in the Duqum region is acceptable for solar energy, and if CSP is used it will help provide adequate amounts of both electricity and desalinated water. There are several good reasons for the implementation of large-scale concentrating solar powered desalination systems:

- Due to energy storage and hybrid operation with (bio)fuel, concentrating solar power plants can provide around-the-clock firm capacity that is suitable for large scale desalination either by thermal or membrane processes,
- Huge solar energy potentials of Oman can easily produce the energy necessary to avoid the threatening freshwater deficit currently estimated at 378 Mm3.
- With support from several foreign countries Oman should immediately start to establish favorable political and legal frame conditions for the market introduction of concentrating solar power technology for electricity and seawater desalination. (Gastli et al. 2010, p. 6)

Qatar

Energy City is currently being built in Qatar. Energy City will encourage multinational natural gas and oil companies to set up headquarters in Qatar. Solar energy will be used in some parts of the city. The project developer sees Energy City as a unique new project that will bring together a traditional oil country in a green environment showcasing to the world that traditional energy sources and green technology can coexist (Reiche, 2009).

United Arab Emirates

According to Islam et al., (2009) the United Arab Emirates (UAE) is blessed with an abundance of solar energy in addition to fossil fuel. Daily average solar radiation data shows that average values are higher in the summer from April to August and are comparatively lower in the winter. Shams 1 is project situated in Abu Dhabi in United Arab Emirates, Shams 1 will be the biggest Concentrated Solar Power (CSP) plant in the Middle East (Figure 25). It will expand over an area of 2.5 km^2, with a capacity of 100 MW and a solar field consisting of 768 parabolic trough collectors to generate renewable electricity (Masder, Media Center).

Figure 25 Shams 1 project (http://www.saudisolarforum.org/wp-content/uploads/2012/03/Yousif-Al-Ali-SHAMS-One-Development-Challenges.pdf)

This project is expected to launch Abu Dhabi into satisfying its 7% green energy guarantee by 2020. The solar collection farm contains a total of 87,777 solar energy production units arranged strategically so as to harness as much insolation from the sun as possible. The yearly output of the power generation farm is expected to be 17,500 MWh. The emission reduction venture are equal to 15,000 tons of carbon per year (Environmental Power Systems, 2012).

An additional project is developing in a Swiss-designed artificial island in Ras al Khaimah, UAE, with the aim of providing 1 MW solar**.** The project is a collaboration between Neuchâtel's Swiss Center for Electronics and Microtechnology (CSEM) and the local government of UAE (Figure 26). This prototype project is now underway and it will have a diameter of 100 meter, one-tenth of the size of an actual solar island. The island will produce electricity by heating up water to produce vapor and will be able to propel itself in case bad weather strikes (AlNasser and AlNasser, 2009)

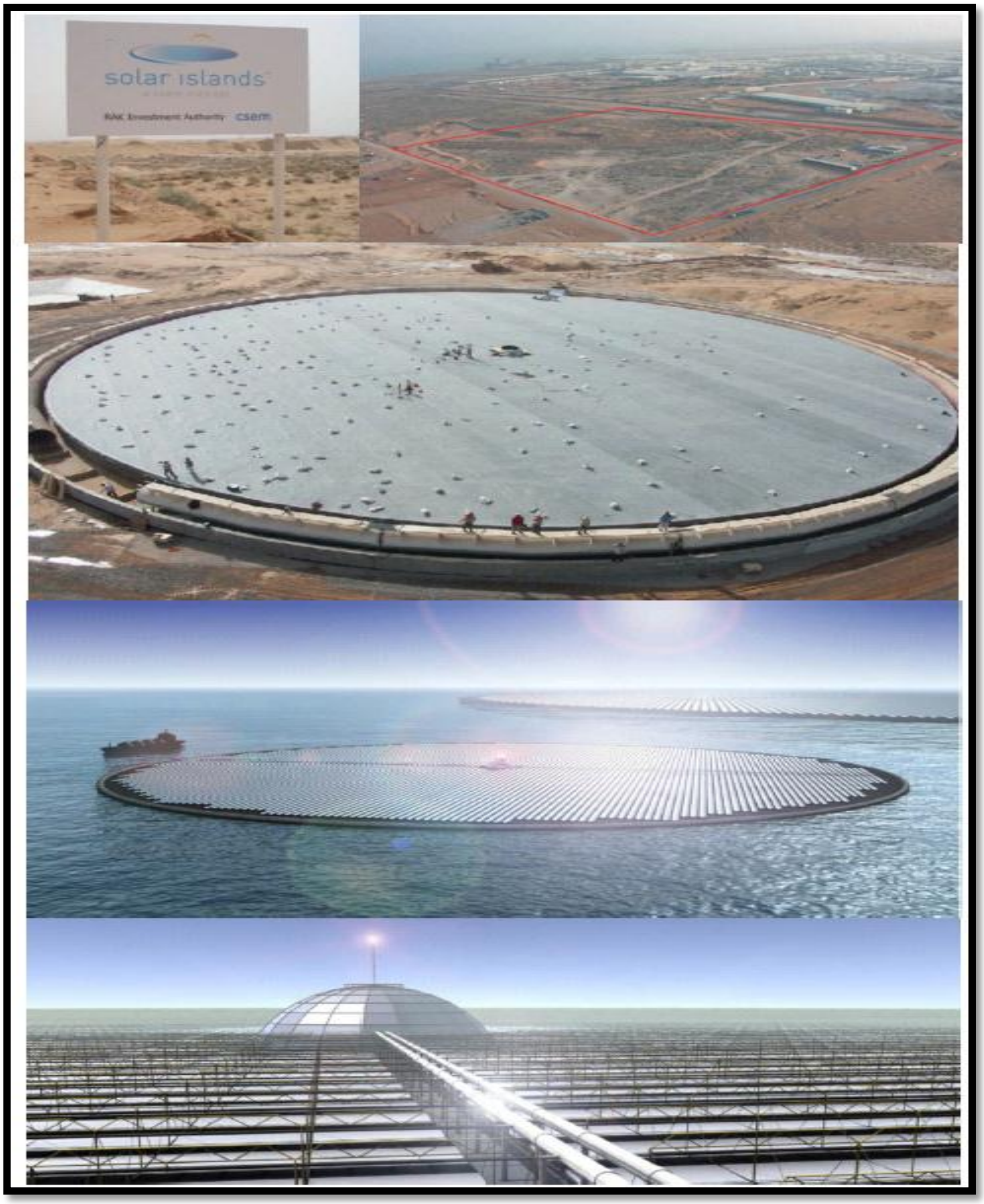


Figure 26 The circular Solar Islands in Ras Al Khaima, UAE. The platform can be floated on high sea or land (AlNasser and AlNasser, 2009)

With hydrocarbon resources fast declining worldwide and concerns about finding alternative sources of energy, and the anxiety to construct a green environment, countries across the globe have begun to more extensively turn to renewable energy sources. For the GCC the most common approach is to use solar energy. While hydrocarbons continue to dominate the primary energy source for the GCC and its construction sector, the economies are definitely rethinking their strategies and aiming at increasing the shares of renewable energy in their energy mix in the future.

Chapter 3

Solar and Hybrid analysis

The objective of this chapter is to examine the potential performance of solar and hybrid energy as well as the levelized cost of electricity of these types of energy for Kuwait. Each type of energy potential is categorized by three criteria: area potential, technical potential, and economic potential. The area potential includes the geographical areas suitable for installing the PV/CSP modules. The technical potential includes the system performance of these modules, and the economic potential includes the cost analysis of PV/CSP technologies.

Estimation of solar radiation is considered as the most important parameter for the design and development of various solar energy systems. The foremost objective of the present study was to present a simple formulated approach for hourly global solar radiation intensity on horizontal surfaces at the earth's surface (Liu et al., 2009). This approach will be modified, taking into consideration Kuwait's geographical parameters and its climate conditions.

The level of solar energy density in Kuwait is among the highest in the world (Ramadhan and Naseeb, 2011). There is significant scope for developing solar energy resources throughout Kuwait, and solar energy has the potential to provide sufficient electricity to meet all of Kuwait's domestic electricity requirements and provide some electricity for export.

Meteorological data

Data for this study was obtained from the Kuwait Institute for Scientific Research (Table 5). Solar radiation maps will be developed for Kuwait to demonstrate the geographical distribution of solar radiation covering Kuwait. A solar radiation map shows solar energy potential of Kuwait by providing all the information and developing a solar radiation database. Figure 27 shows the nine solar stations that will be analyzed in this study.

Table 5 Locations of the solar data stations (Data for this table obtained from National Meteorological Network (KISR) and Kuwait Meteorological Department)

STATION NAME	LONGITUDE (DD MM SS)	LATITUDE (DD MM SS)
Salmi	46 40 54	29 06 04
Wafra	48 00 29	28 37 01
Ras As-Subiyah	48 05 00	29 34 55
Al-Mutla	47 37 05	29 22 54
KISR	47 54 37	29 20 02
Um Omara	47 06 00	29 07 33
Um Al-Haiman	48 08 22	28 56 35
Al-Taweel	47 52 29	28 55 18
Ras Az-Zoor	48 21 29	28 44 46

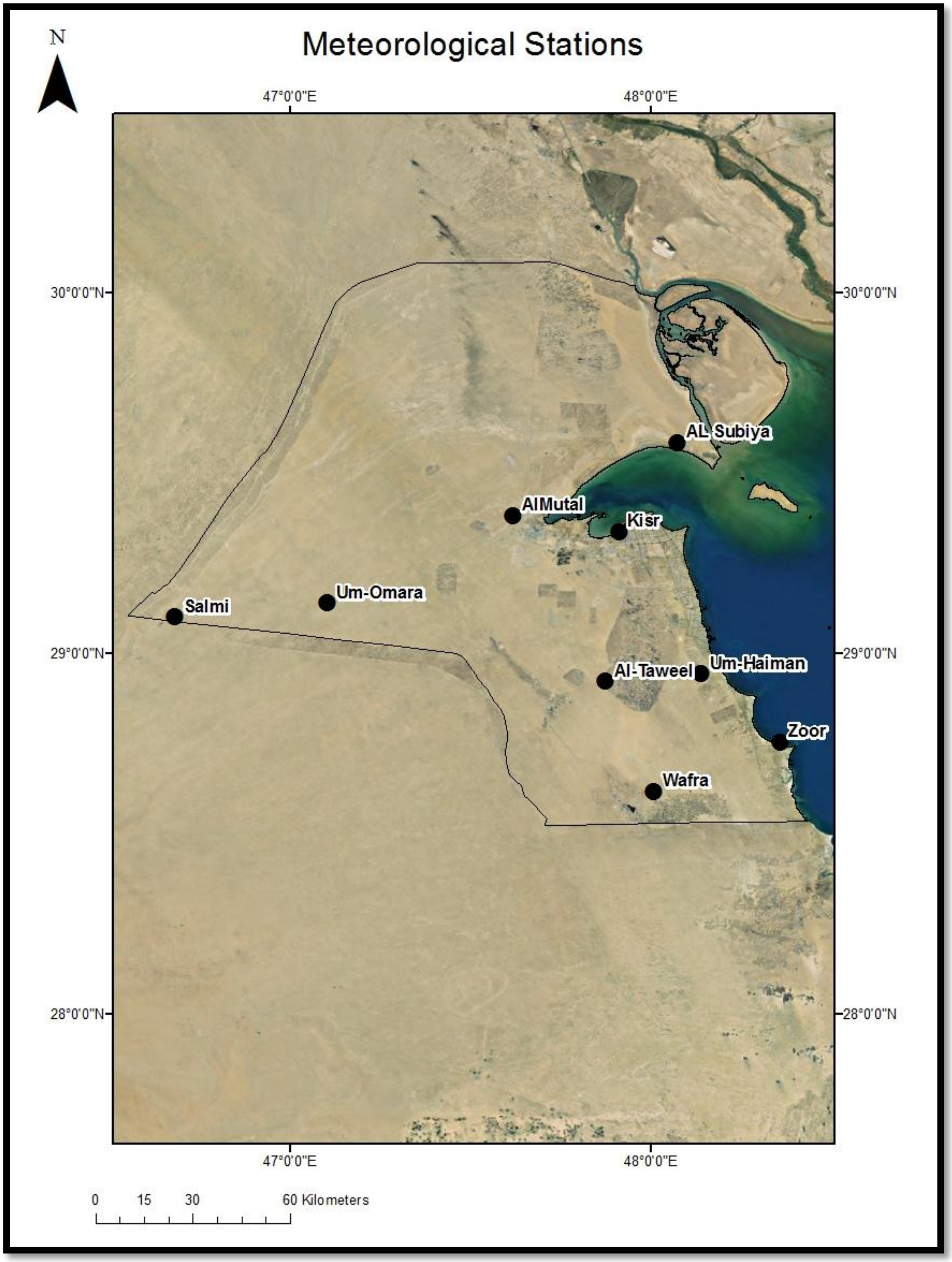


Figure 27. Kuwaiti Solar Stations Map

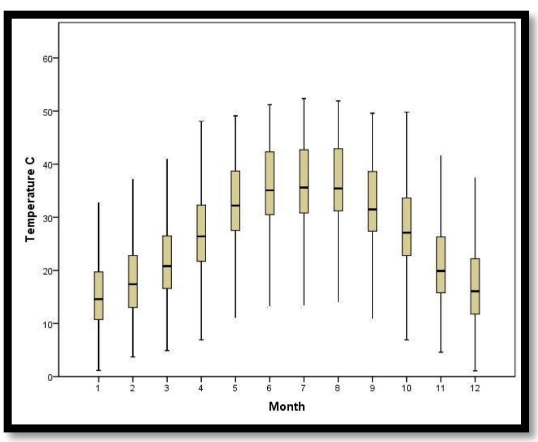
Solar data analysis

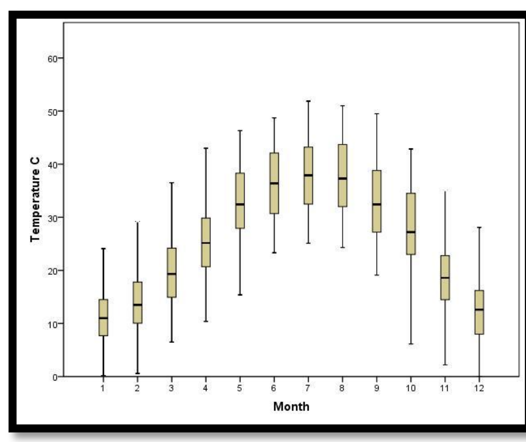
Solar panel temperature is one of the important factors that impacts how much electricity the panels will produce. The solar panel temperature affects the maximum power output directly. As solar panel temperature increases, its output current decreases exponentially while the voltage output is reduced linearly. The following (Figures 28, 29) demonstrate the monthly temperature for Wafra and Um-Omara to analyze how the temperature will affect the amount of generated electricity. Since the temperature increases significantly in summer, Kuwait could follow the Maser City footstep by adding a wet cooling system with treated wastewater from a nearby sewage treatment plant to help keep the solar panel cool and minimize the losses of electricity production (Moghbelli and Vartanian,2006).

The locations Wafra and Um-Omara were chosen to examine the temperature patterns. Choosing stations from different locations with different characteristics will help to demonstrate the temperature pattern during the summer months when electricity reaches its peak.

Figures 28 and 29 illustrate the variation of temperature with hourly values for each month in Wafra and Um-Omara. The temperature in Wafra reaches its maximum of 51^{o} C in June and minimum of 1 ^{o} C in December, with an average of 26° C. In Um-Omara the temperature reaches its maximum of 52 ^{o} C in June and minimum of -1 ^{o} C in December and January.

The intensity of solar radiation and the length of the day cause rapid temperature increases due to the combinations of decreased cloud cover and normal weather conditions, especially in the Summer. Temperature begins to increase in February. The hot south (Al-Suhily) wind blows during the period from 15 March – 10 April and lasts for several days, and the maximum temperature may reach 41° C. In the transition period from May to June, winds are characterized by unstable directions as they swing between south and east, northwest and southeast, and light to moderate. This period is the transition period between the late spring and the real summer, with the maximum temperature ranging between 40° and 44° C, and sky is usually clear of clouds (U.S. Marine Corps, 1990).





Figures 28 and 29 Monthly version of temperature at Wafra and Um-Omara

This section demonstrates the statistical analysis for solar radiation and power production. The results show that several locations can reasonably be considered as favorable for electricity production. This research analyzed 13 years of hourly data. Yearly solar radiation from Mutla is presented in Figure 30.

Solar energy is possibly the most suitable as a renewable energy alternative, as the average hourly solar radiation for Kuwait is high compared with countries that are currently among the main users of solar energy, such as Germany and Spain (Table 6).

Table 6. Essential Comparisons for analyzing solar power potential (Katilaine, 2009).

Countries	Avg max day temp (^{0}C)	Avg min day temp (^{0}C)	Avg daily hours of sunshine	Total rainfall per year (mm)
Manama, Bahrain	30.8	22.5	9.3	84
Kuwait City, Kuwait	32.2	19.3	8.9	111
Muscat, Oman	32.8	23.4	9.6	103
Doha, Qatar	32.4	21.8	9.5	74
Riyadh, Saudi Arabia	33.0	18.4	9.3	112
Abu Dhabi, United Arab Emirates	33.3	21.8	9.5	57
Granada, Spain	20.3	6.8	7.8	483
Lisbon, Portugal	22.4	12.9	4.3	743
Berlin, Germany	13.0	5.2	4.6	576

Figure 30 represents yearly variations of daytime hourly solar radiation. A steady value decrease in both 2002 and 2009 was due to either cloud cover or dust storms during the year.

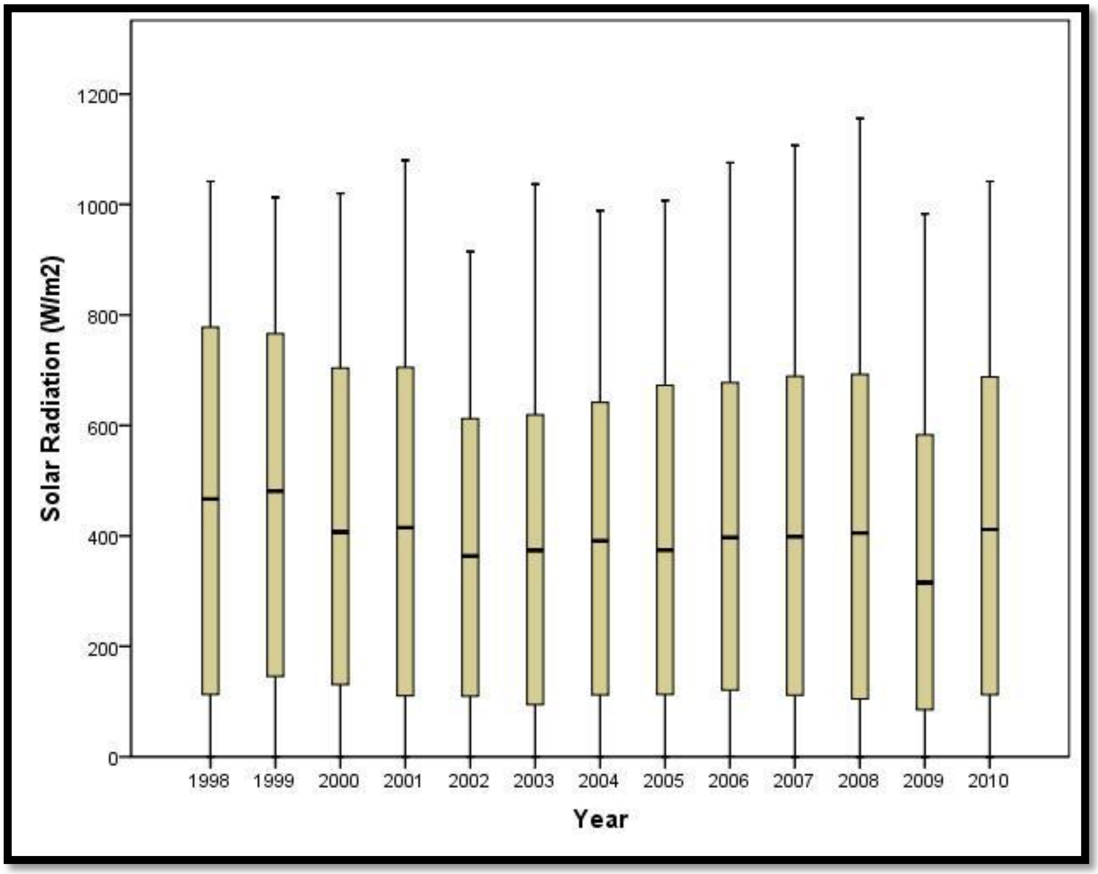
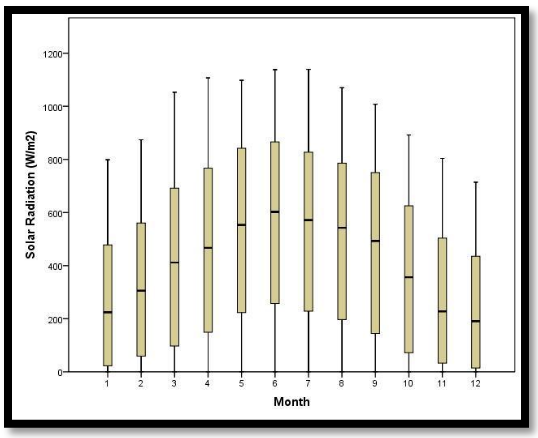
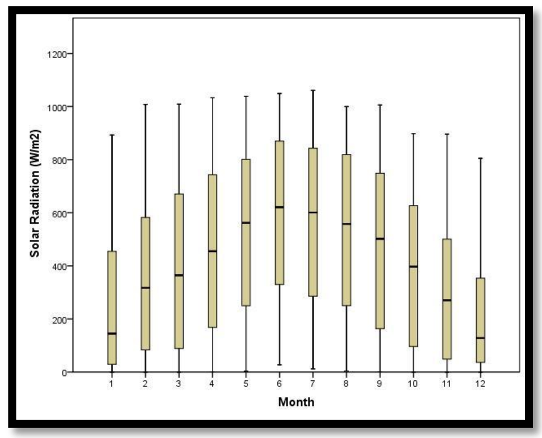


Figure 30 Yearly solar radiation in Mutla from 1998 to 2010.

The monthly patterns for solar power generation in Kuwait are in line with the national power demand. A solar power system is likely to deliver maximum power output during the peak summer season coinciding with the national peak power demand period. This makes solar farms excellent devices for meeting peak power demands. Figure 31 demonstrates the highest monthly average is 714 W/m^2 in June, and the lowest is 250 W/m^2 in December. Figure 32 represents the solar radiation for KISR, which is located in the Kuwait city area, with a maximum of 1049 W/m^2 and an average of 583 W/m^2 in summer months and a monthly average around 210 W/m^2 in winter months. Kuwait receives the highest daily solar radiation, especially during the summer months (April-August) when the sunlight is at its highest for the maximum number of hours.





Figures 31 and 32 Monthly solar radiation in Subiya and Kisr from 1997 to 2010.

Figure 33 shows the average hourly solar radiation data in different parts of Kuwait for 13 years for the months of June and December. The average solar radiation is highest at 583 W/m^2 west of the Kuwait City area and lowest in the costal area, since the larger body of water can affect the climate of coastal areas by absorbing or giving off heat.

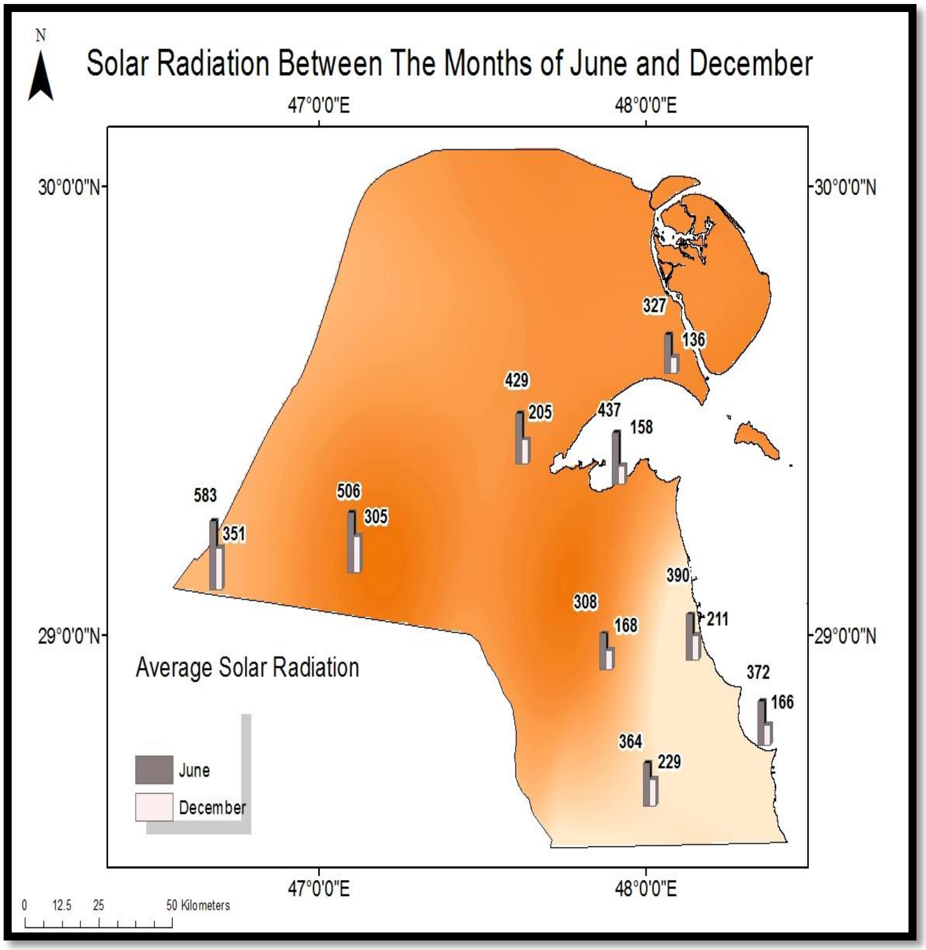


Figure 33 The average daily solar radiation for June and December

Estimation of electricity generation capacity and potential

Kuwait is in an advantageous position with solar energy; it belongs to the global Sunbelt (Figure 34; Comson, 2010). Distribution of solar radiation over Kuwait is shown in Figure 35. It can be clearly noticed which areas demonstrate high solar energy potential. The solar map indicates that Kuwait, as one of the sun-belt countries, is endowed with high yearly intensity solar radiation. It is possible to estimate yearly solar electric power generation potential of the country or a region based on an equation using the calculated yearly solar radiation per unit surface, the total exploitable area, and the efficiency of the technology used to convert solar energy. Tables 7 and 8 can be used to estimate the yearly solar electric power generation potential (Gastli and Charabi, 2010):

$$GP = SR \times CA \times AF \times \eta \qquad (1)$$

Table 7. Equation Parameters obtained from Gastil and Charabi, 2010

PARAMETER	DEFINITION	UNITS
GP	The electric power generation per year	KWh
SR	The solar radiation received per unit horizontal area	$KWh/m^2/year$ (to calculate annual electricity production)
CA	The calculated total area	m^2
AF	The area factor, indicates what fraction of the calculated areas are covered by solar panels	Unitless
η	The efficiency with which the solar system converts sunlight into electricity	Unitless

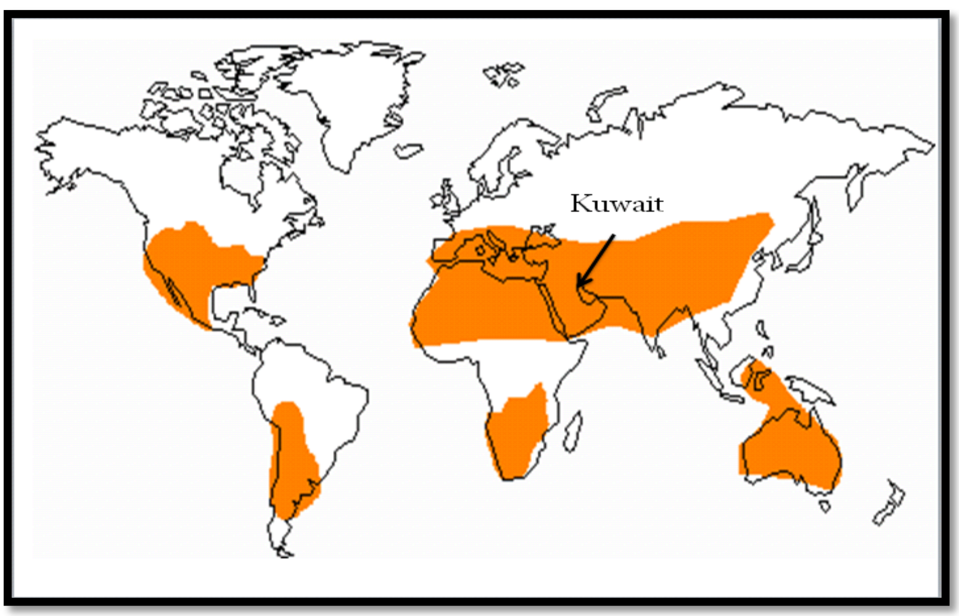


Figure 34. Solar Belt Countries (Comson, 2010).

The potential generation of the capacity (KWh/year) shows the annual electricity production over Kuwait. It can be clearly noticed which area demonstrates high solar energy potential (Figures 37 and 38). For these highly suitable levels it PV/CSP technologies are presented in Tables 9, 10. An area factor of AF=70% was selected based on maximum land occupancy of PV/CSP panels with minimum shading effect. Areas of at least equal or larger than 2,500,000 m^2 were selected. These numbers are based upon other academic research in Oman (Gastli and Charabi, 2010). The efficiency, η, of each PV/CSP technology was considered for a typical region having high temperature and solar radiation such is the case for Kuwait, and based on the other projects such as 100 MW CSP Shams 1 and 10 MW PV Masder City Farm in United Arab Emirates.

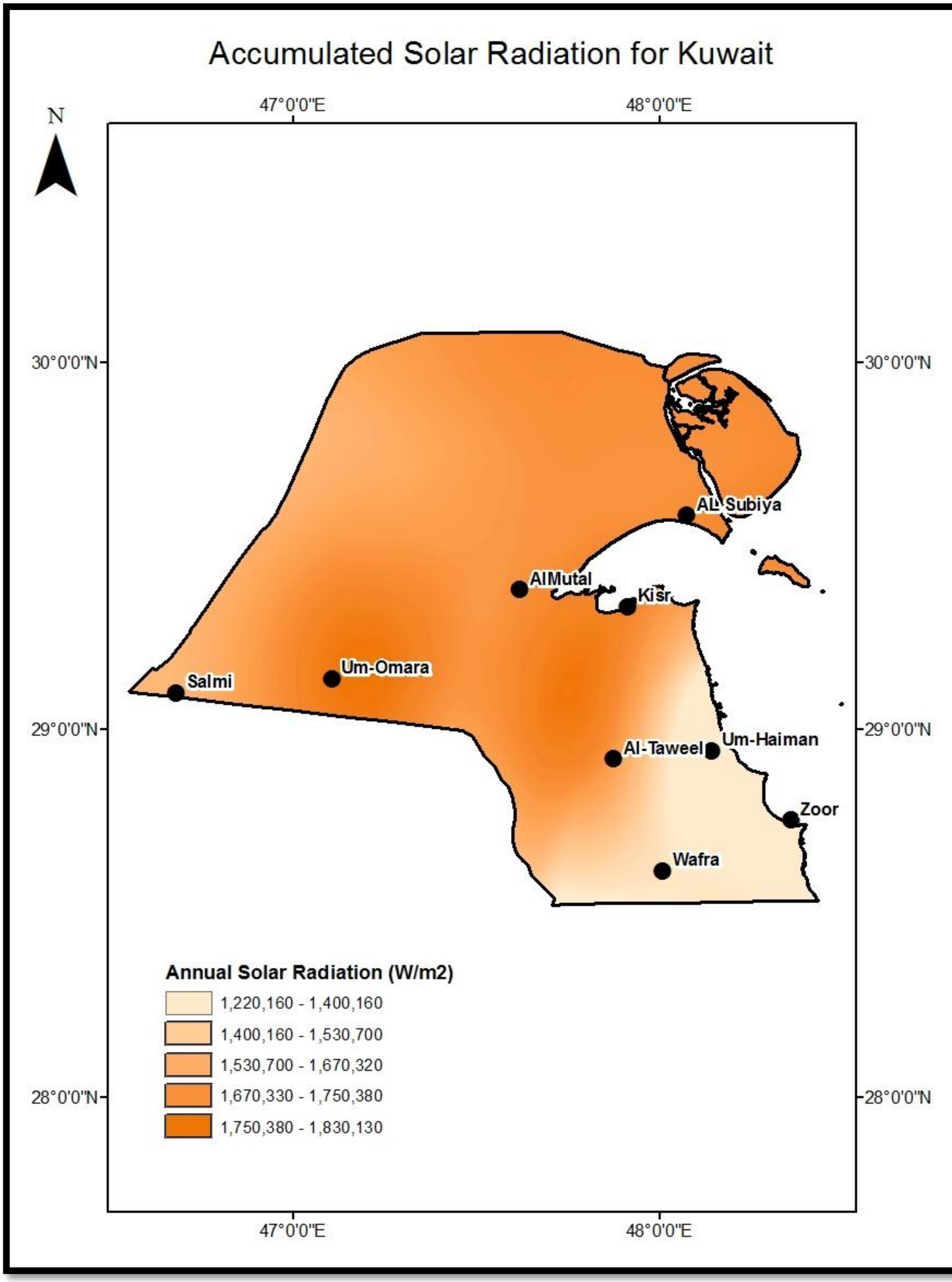


Figure 35 Annual solar radiation of Kuwait

Figure 36 represents the potential kWh in Mutla and Subiya by using two different solar energy technologies, PV and CSP, with a maximum in June for PV of 358,470 kWh and for CSP of 418,215 kWh, and a maximum in December of 224,910 kWh for PV and 262,395 kWh for CSP. For Subiya, the pattern for potential kWh in Kuwait meets the national power demand. With the average in June of 221,679 kWh for CSP and 262,395 kWh for PV and the average for December of 3,775267 kWh for CSP and 6,112337 kWh for PV. There is a visible decrease in the kWh production during the months of July and August due to higher temperature. Figures 37 and 38 represent the hourly kWh potential for solar energy. Both maps indicate areas with high potential of 410,480,990 to 520,540,430 kWh by using a PV system and 540,630,430 to 630,550,140 kWh by using CSP for Salmi and al Subiya.

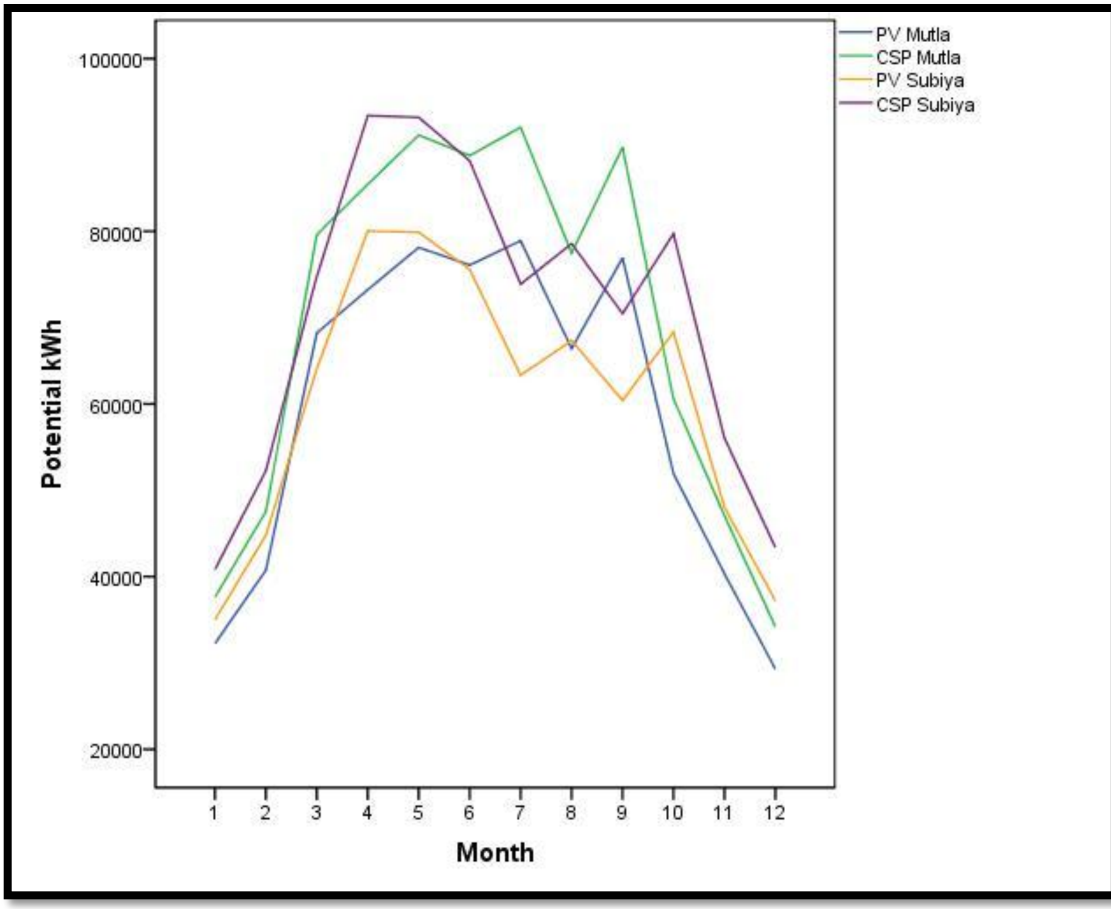


Figure 36 Monthly variations of kWh potential by using PV/CSP technologies at Mutla and Subiya

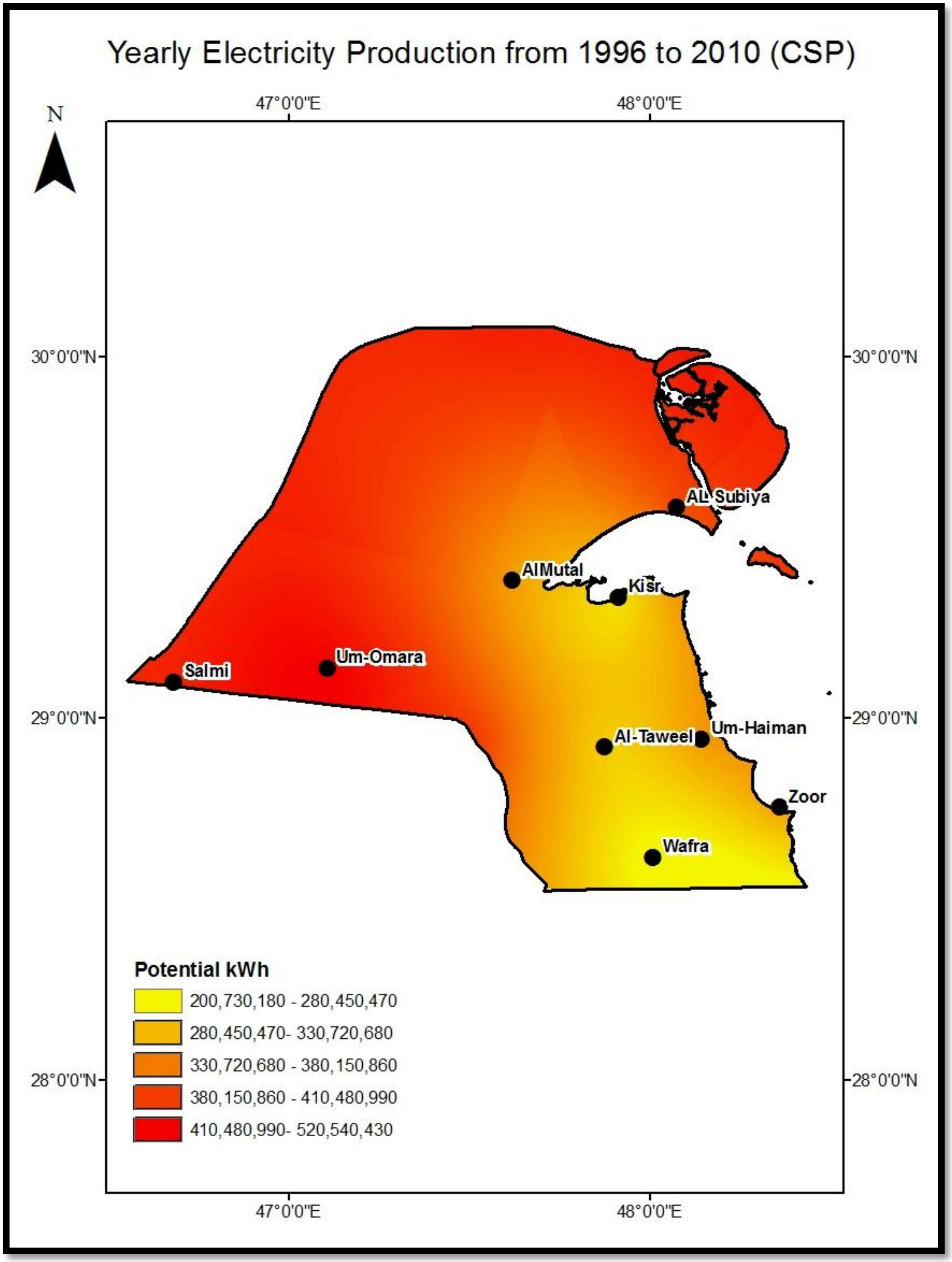


Figure 37 Annual estimated CSP-generated electricity production in Kuwait

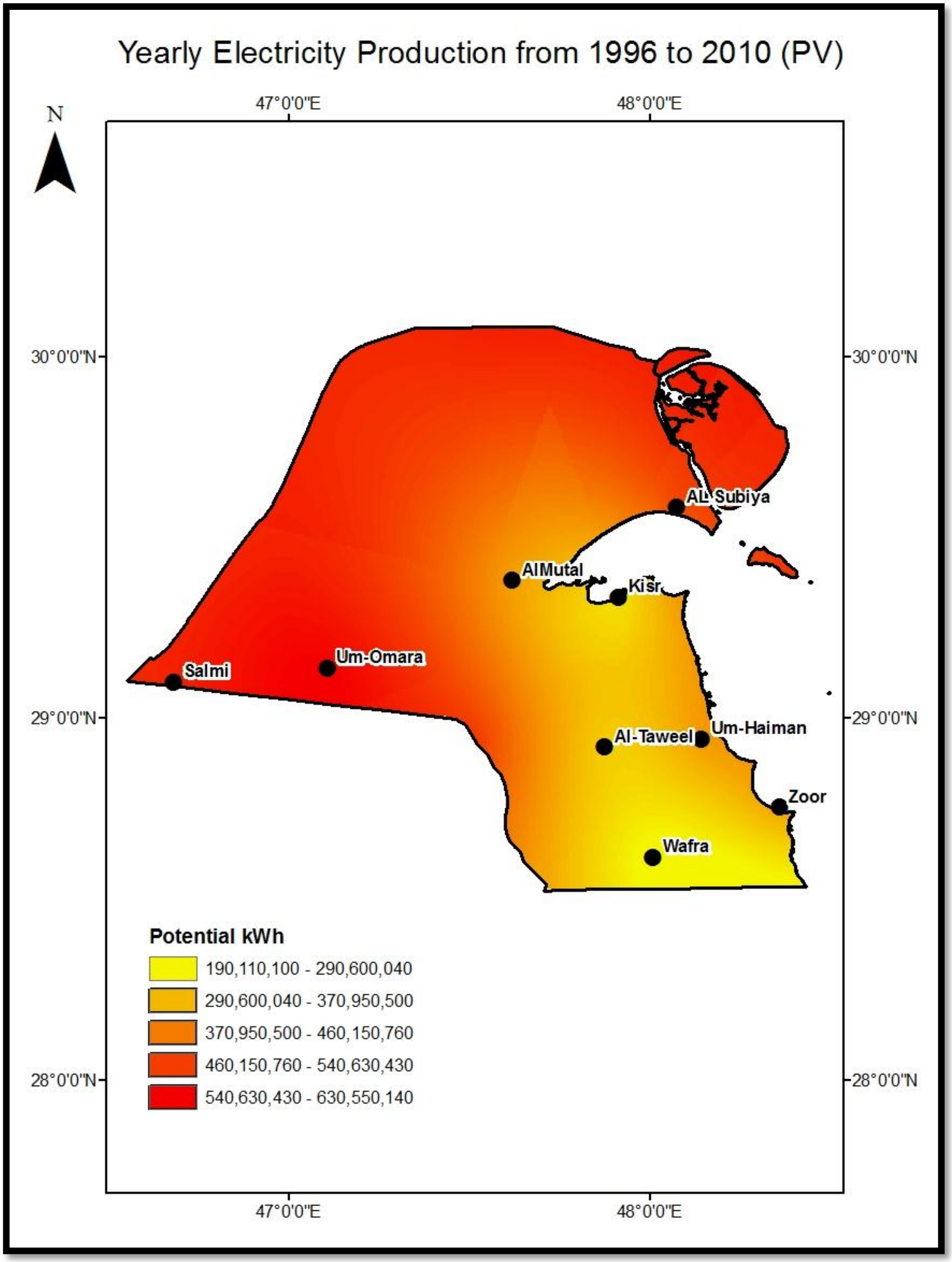


Figure 38 Annual estimated PV-generated electricity production in Kuwait

Table 8 Equation Parameters For Kuwait 100 MW Farm

Solar Technology	AF	Efficiency	Suitable Land (CA/ m^2)
Crystalline Silicon	70%	18%	2500000
CdTe		16%	
Parabolic Trough Collectors		21%	

Table 9 Total generation potential on highly suitable lands

Station	Annual generation potential (kWh/year)
Um-Omara	572,040,000
	508,480,000
	667,380,000
Subiya	545,895,000
	485,240,000
	636,877,500
Wafra	447,615,000
	397,880,000
	522,217,500
Taweel	527,625,000
	469,000,000
	615,562,500
Mutla	500,220,000
	444,640,000
	583,590,000

The basics of solar technology economics

Solar energy is perhaps the most appropriate for the climatic condition in Kuwait (see Table 1). The average daily irradiation is very high compared to other countries. Kuwait has a great potential for solar thermal power plants due to its high average daily irradiation and high ambient temperature. Photovoltaic (PV) and Concentrate Solar Power (CSP) can impart critical solutions to electricity provide in Kuwait contained by reasonably short time frame (Ramadhan and Naseeb, 2011).

The levelized cost of electricity (LCOE) can be used as a ranking tool to evaluate the cost-effectiveness of different energy generation technologies. The abstraction is made to remove biases among the technologies. LCOE is an approximate benchmarking tool. Typically, LCOE is a static measure that looks at a snapshot in deriving the price per generated energy, whilst true markets prices are dynamic (Table 10). The economic feasibility of solar technology projects is being evaluated by using LCOE in to contrast it to other methods of evaluating cost of electricity generation (Branker et al., 2011).

Table 10 Direct manufacturing cost and efficiency module cost (Zweibel, 1999).

	$200/m^2	$150/m^2	$100/m^2	$50/m^2
6%	$3.3	$2.5	$1.7	$0.8
8%	$2.5	$1.9	$1.35	$0.63
10%	$2	$1.5	$1	$0.5
12%	$1.7	$1.25	$0.83	$0.42
15%	$1.7	$1	$0.67	$0.33

The essential economic concept for any technology installation is that its cost should be recovered by the useful energy it produces over its lifetime. The levelized cost of electricity (LCOE) can be estimated from the ratio of the total life cycle cost to the total lifetime energy production to the following equations for 100 MW PV/CSP station:

1. Capital Cost for Crystalline Silicon 2.5$/W and CdTe 2$/W (Wohlmuth, 2009), and Parabolic Trough Collectors 4.6 $/W (Mokri and Emziane, 2011).
2. Station Annual output = Annual solar radiation X Model Efficiency X Station Capacity (m^2)
3. Installation Cost = Capital Cost X Station Capacity
4. Annual Cost = (Installation Cost X Capital Recovery Factor (CRF)) + Operation and Maintenance (O&M)

- $$CRF = \frac{i \times (1+i)^n}{\left[(1+i)^n - 1\right]}$$

- Where i is interstate rate and n is project life.

- Operation and Maintenance (O&M) Many industries estimate maintenance costs using a fixed percentage 3-4% of initial capital cost as the expected annual maintenance cost of equipment. This may appear small, but since dividing by a depreciation period (20 yrs) does not reduce it, it is actually quite similar to the amortized capital cost (Zweibel, 1999).

5. LCOE = Annual Cost/ Annual Output of the Station

Table 11, demonstrates the how the parameters of LCOE equation will apply to each station respectively Um- Omara, Mutla,Taweel, Wafra and Subiya station***.

Table 11 LCOE Parameters for Solar Farm in Kuwait

<table>
<tr><th>Station</th><th>Efficiency</th><th>Project Life</th><th>O&M</th><th>Interest Rate</th><th>Station Capacity</th></tr>
<tr><td>Um-Omara</td><td rowspan="5">PV-Si 18%

PV-CdTe 16%

CSP 21%</td><td rowspan="5">20 years**</td><td rowspan="5">(3% of installation Cost Per Year) **</td><td rowspan="5">5%-10% **</td><td rowspan="5">2,500,000m^2</td></tr>
<tr><td>Mutla</td></tr>
<tr><td>Taweel</td></tr>
<tr><td>Wafra</td></tr>
<tr><td>Subiya</td></tr>
</table>

** Applied parameters in LCOE based on previous work.
*** These areas where because they are most suitable area for solar farms.

Tables 12,13 and 14 demonstrates the results after applying the LCOE to each station with different types of solar technologies

Table 12 LCOE for Crystalline Silicon with efficiency 18% (PV-Si)

Station	kWh without subsides cost in Kuwait	LCOE with 5% Interest rate	LCOE with 10% Interest rate	Cost saving with 5% Interest rate	Cost saving with 10% Interest rate
Um- Omara	0.121$ kWh	0.06 $ kWh	0.09 $ kWh	0.061 $ kWh	0.031 $ kWh
Wafra		0.08 $ kWh	0.11 $ kWh	0.041 $ kWh	0.011 $ kWh
Mutla		0.07 $ kWh	0.10 $ kWh	0.048 $ kWh	0.021 $ kWh
Taweel		0.07$ kWh	0.10 $ kWh	0.048 $ kWh	0.021 $ kWh
Subiya		0.06 $ kWh	0.09 $ kWh	0.061 $ kWh	0.031 $ kWh

Table 13 LCOE for CdTe with efficiency 16% (PV-CdTe)

Station	kWh without subsides cost in Kuwait	LCOE with 5% Interest rate	LCOE with 10% Interest rate	Cost saving with 5% Interest rate	Cost saving with 10% Interest rate
Um- Omara	0.121$ kWh	0.05 $ kWh	0.08 $ kWh	0.071 $ kWh	0.041 $ kWh
Wafra		0.07 $ kWh	0.10 $ kWh	0.048 $ kWh	0.021 $ kWh
Mutla		0.06 $ kWh	0.09 $ kWh	0.061 $ kWh	0.031 $ kWh
Taweel		0.06 $ kWh	0.09 $ kWh	0.061 $ kWh	0.031 $ kWh
Subiya		0.06 $ kWh	0.09 $ kWh	0.061 $ kWh	0.031 $ kWh

Table 14 LCOE for Parabolic Trough Collectors with efficiency 21% (CSP)

Station	kWh without subsides cost in Kuwait	LCOE with 5% Interest rate	LCOE with 10% Interest rate	Cost saving with 5% Interest rate	Cost saving with 10% Interest rate
Um- Omara	0.121$ kWh	0.10 $ kWh	0.14 $ kWh	0.021 $ kWh	-0.019 $ kWh
Wafra		0.12 $ kWh	0.16 $ kWh	0.001 $ kWh	-0.039 $ kWh
Mutla		0.11 $ kWh	0.16 $ kWh	0.011 $ kWh	-0.039 $ kWh
Taweel		0.10 $ kWh	0.15 $ kWh	0.021 $ kWh	-0.029 $ kWh
Subiya		0.10 $ kWh	0.14 $ kWh	0.021 $ kWh	-0.019 $ kWh

Over the years, the demand of electricity in Kuwait has been increasing drastically. Solar energy application such as PV and CSP can produce energy that will meet part of the electricity demand. Furthermore, implementation of solar power will contribute substantially to CO_2 reduction efforts in Kuwait, and can reduce the pressure on current power stations to generate electricity. The analysis shows that the positive characteristics of solar radiation in Kuwait play a role in enhancing the feasibility of implementing solar systems. The feasibility of a 100 MW PV/CSP station can be achieved under the present price (Tables 12, 13, 14), the LCOE for PV (Crystalline Silicon) farm 0.06 to 0.08 $ kWh with 5% interest rate and 0.0.09 to 0.11 $ kWh with 10% interest rate. Finally, implantation of solar energy can decrease dependence on fossil fuel to produce electricity, which will set Kuwait among the pioneers within oil exporting countries in utilizing renewable energy for domestic consumption. Based on this analysis the study recommends the implementation of solar system in Kuwait in order to diversify sources of energy.

Interpolation between Stations

Developing solar radiation maps for a given region means creating illustrations revealing the geographical distribution of solar radiation covering Kuwait. A solar radiation map provides information for optimal site selection of a solar energy system and other renewable energy systems. Solar radiation data obtained from KISR stations are used to produce the solar radiation map. Variations in slope (Figure 8) and elevation influence the solar radiation amount received at different locations. Using the kriging method of surface interpolation is a way to produce prediction, probability, or standard error maps. The error map in Figure 39 reflects data locations, not data values. It is shown that the prediction of error is close to zero around the station locations, but worse in the edge and north part of the country, with values up to +90%. The actual value for points location much lower but values or smoothed interpolation for improved graphical interoperability.

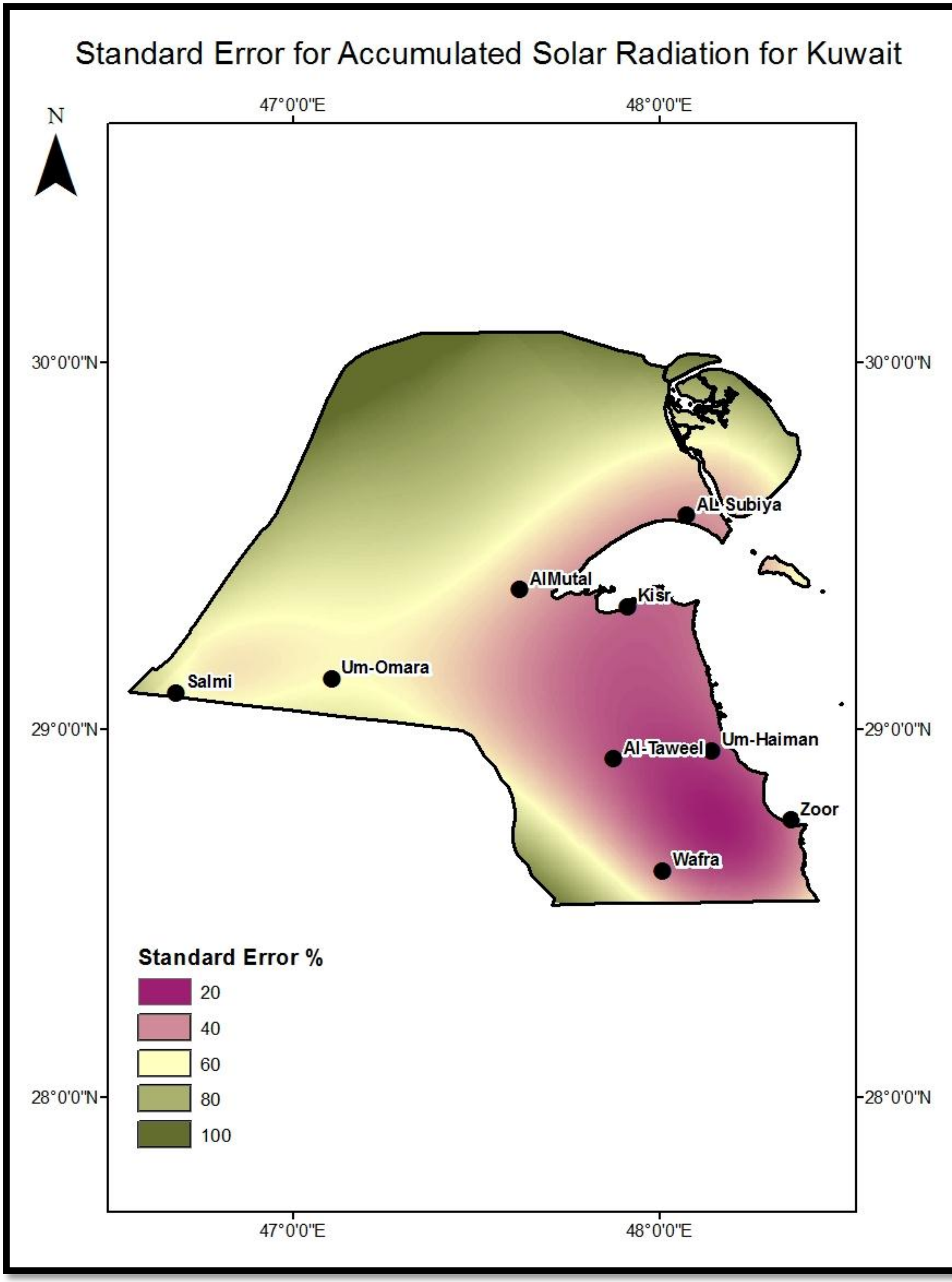


Figure 39 Standard Error Map for Solar Radiation Data

Viable locations for utilization solar farms and hybrid system farms

Large-scale PV/CSP farms require flat terrain or a slope with less than a 5% grade (Gastli and Charabi, 2010), In Kuwait slopes range from 0 to 2.7%. Land suitability analysis for large PV farms implementation was carried out for areas of Kuwait. The results obtained from the analysis of the resultant maps showed that a considerable portion of the land demonstrates high suitability (Figure 40). Besides, the results obtained will certainly facilitate the planning of new transmission lines, attract more solar project developers to build solar PV generation facilities, produce clean and reliable electric power in the country to meet growing energy needs, and create a valuable product to export to other countries, especially after the interconnection between Kuwait and other GCC countries. Figure 40 will be combined with wind results previously analyzed in Figure 16 to develop a hybrid analysis.

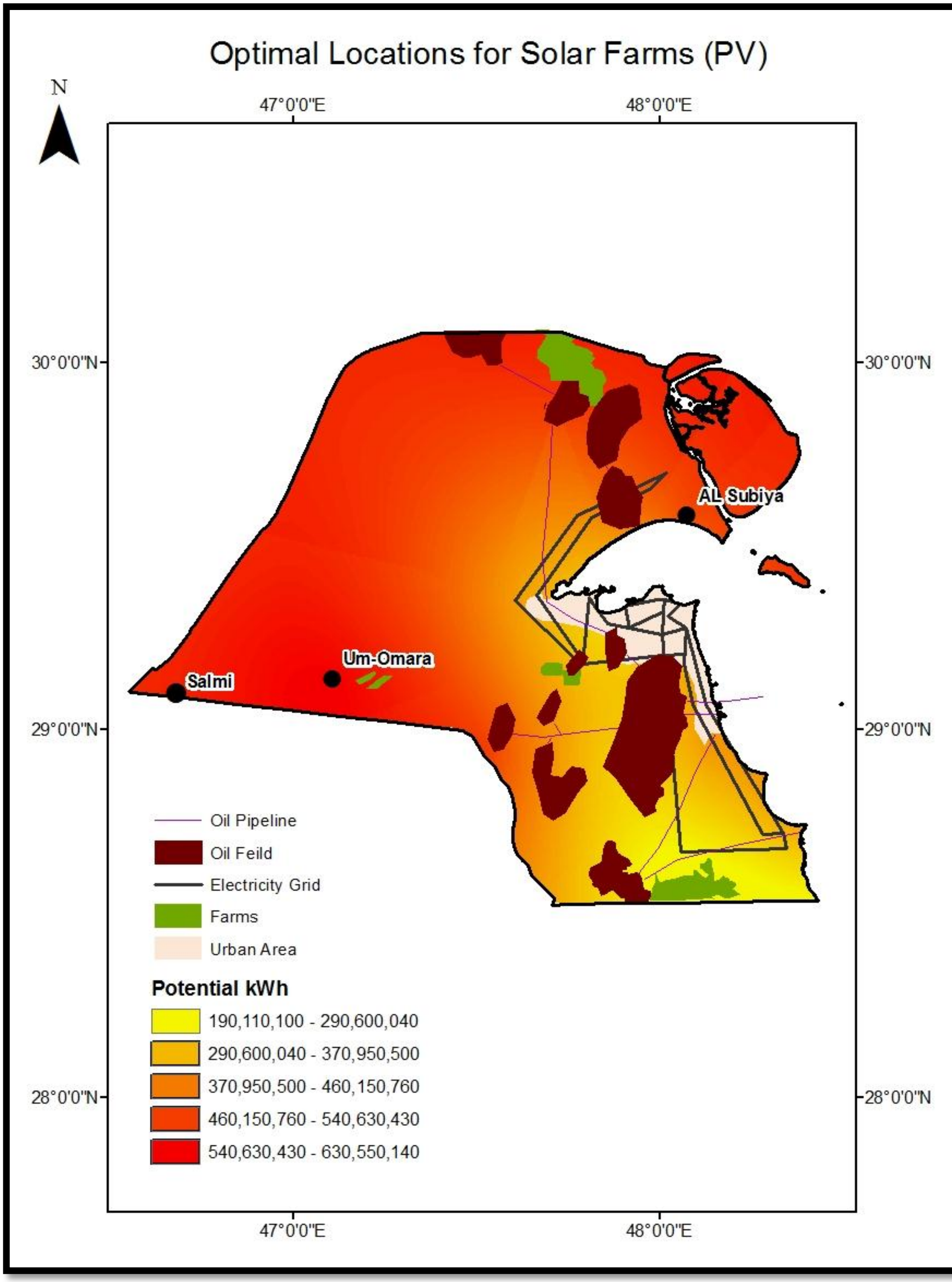


Figure 40 Optimal Locations Solar Farms PV

Hybrid system (combining wind and solar energy)

Solar and wind energy are site dependent, non-polluting, and potential sources of alternative energy options. Combining renewable energy hybrid systems (Figure 41) is the schematic layout of solar and wind hybrid systems that can supply either DC or AC energy or both. Kuwait will receive the benefit from both energy options and improve energy production stability because we cannot collect solar energy at night or during cloudy weather. On the other hand, wind energy is available much of the time.

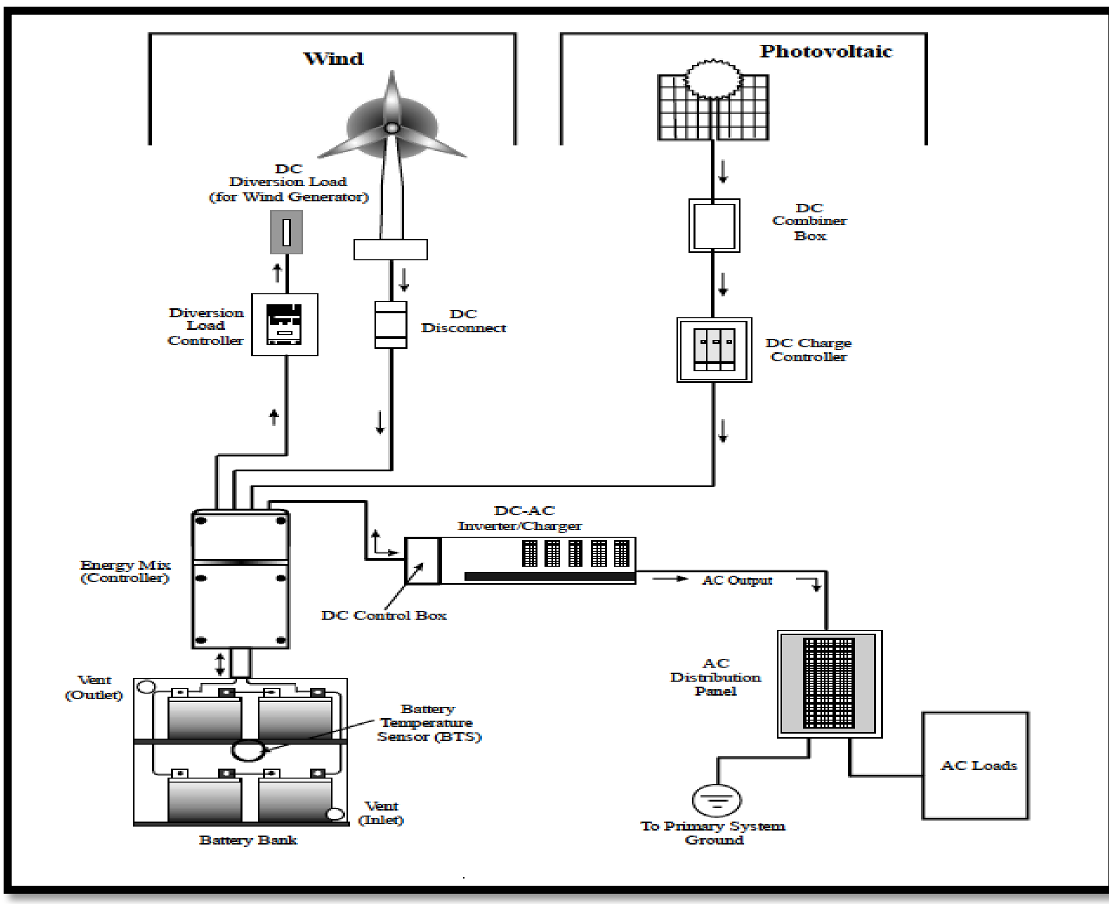


Figure 41 Schematic diagram of Hybrid (Renewable) Solar, Wind Power (Adejumobi et al., 2011)

The integration of renewable energy such as solar and wind energy is becoming increasingly attractive. Wind energy can be used in Kuwait by hybridizing it with another abundant energy source like solar energy; by integrating it with proper electric energy storage, a reliable and efficient renewable electric power plant can be obtained.

Dharhran is a city located in Saudi Arabia that is blessed with high isolation level and an ample wind regime. A considerable amount of its energy requirement may be harnessed from the hybrid combination of wind and solar energy (Elhadidy and Shaahid, 2000). This paper investigates the energy generated by hybrid systems (wind, solar), which is simulated by diverse combinations of 10 kW WECS and PV panels supplemented with a battery storage system and diesel back-up. The energy generated from the backup-diesel generator is used at times when the output from wind and solar systems fails to satisfy the load and when the battery storage is depleted (Elhadidy and Shaahid, 2000).

Yang and Burnett (2003) investigate the development of solar –wind hybrid energy in Hong Kong. Their approach is to design a hybrid system by using linear programming, goal programming and probabilistic techniques is called Loss of Power Supply Probability (LPSP). In order to calculate the probability analysis of hybrid photovoltaic wind power generation systems or to predict energy consumption or energy generated from a system in the design stage, meteorological data is required to provide the hourly data for solar radiation and other meteorological parameters (Yang and Burnett, 2003).

Hybrid analysis

This section proposes a combined wind/solar hybrid system. he hybrid power plant consists of the following systems 70% solar energy (CSP and PV) and 30% wind energy GE 1.5 wind turbine as proposed in one the proposals received by the Kuwait Partnerships Technical Bureau to develop a hybrid power plant in Kuwait (Bachellerie, 2012).

At Subiya (Figures 42), which is one of the study sites to examine the optimal location for hybrid system, solar and wind kWh (hourly measurements for each month), were generally higher in summer months with maximum capacity of 286,430 kWh for PV+ GE and 334,168 kWh for CSP+ GE. Figure 43 demonstrates the potential kWh production by using the hybrid system. Both wind speed and solar radiations are greater in summer months, which reflect the higher potential to generate more electricity with 133,444 kWh by using both GE turbines and PV, while the average drops to lower in winter months with 100,760 kWh.

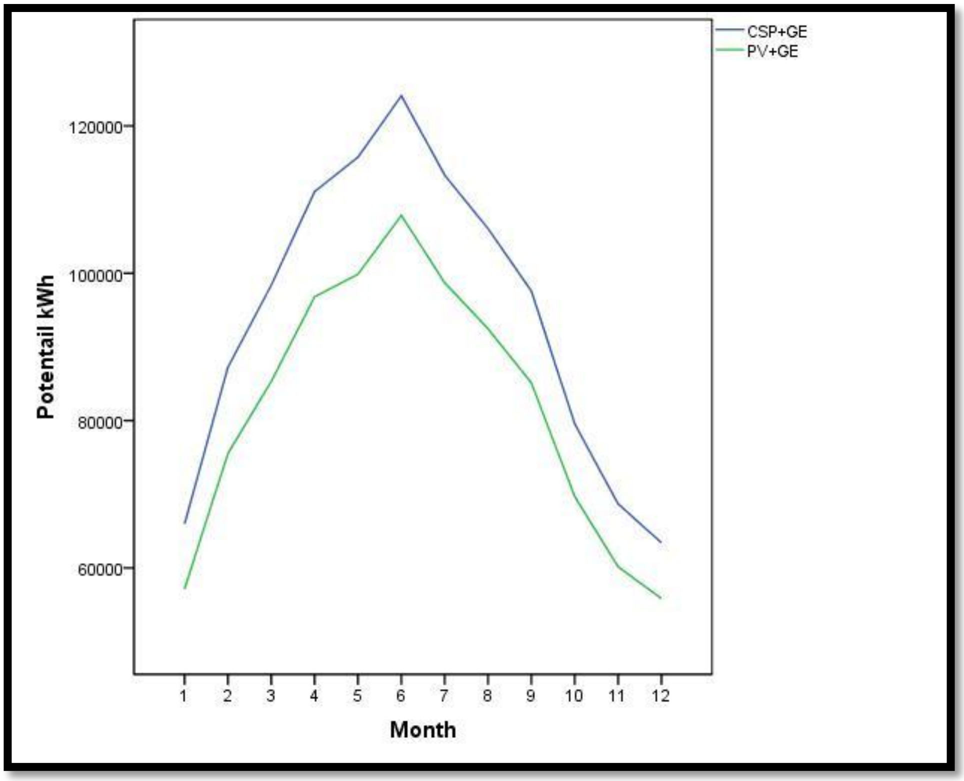


Figure 42 Potential kWh production by using hybrid system (GE wind turbine and PV/CSP) in Subiya

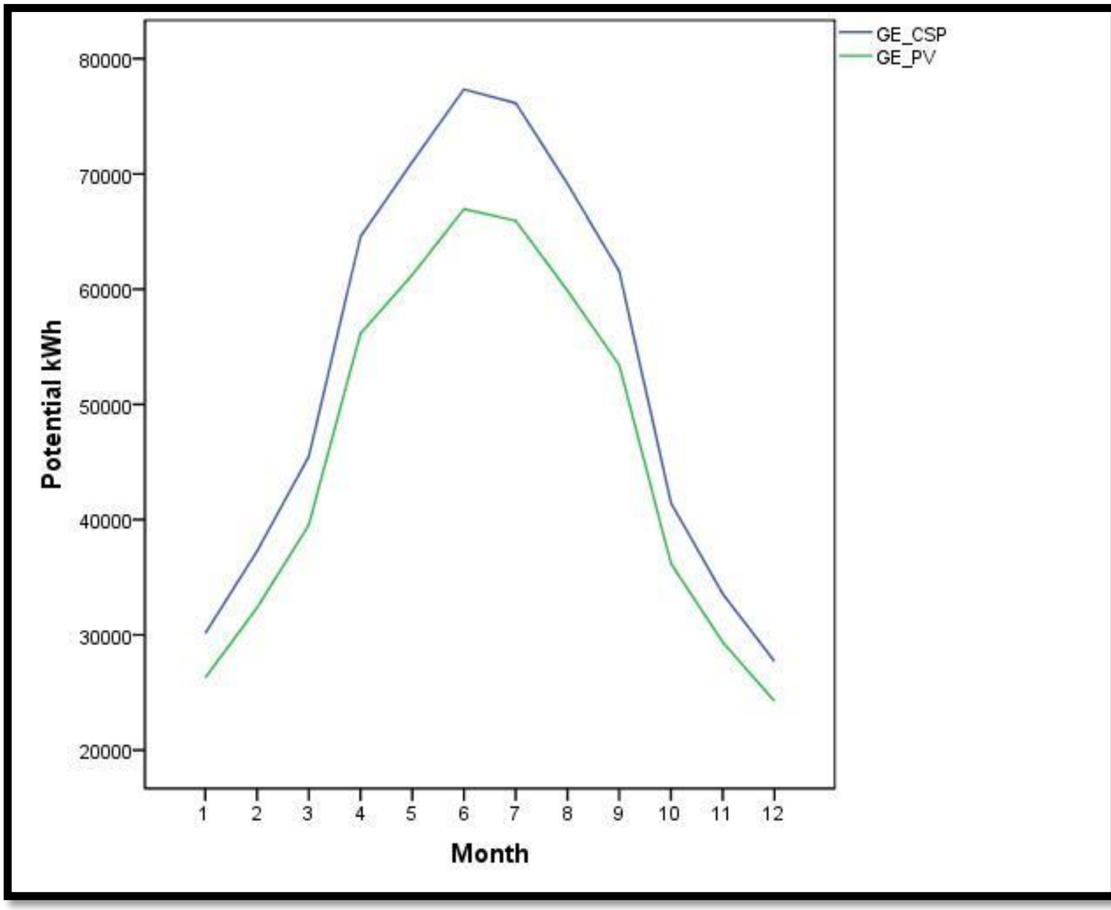


Figure 43 Potential kWh production by using hybrid system (GE wind turbine and PV/CSP) in KISR

Figures 44 and 45 represent the hourly kWh potential for both solar energy technologies PV and CSP combined with wind energy. Both maps indicate areas with high potential of 340,500 to 467,260 kWh in Subiya, and Salmi.

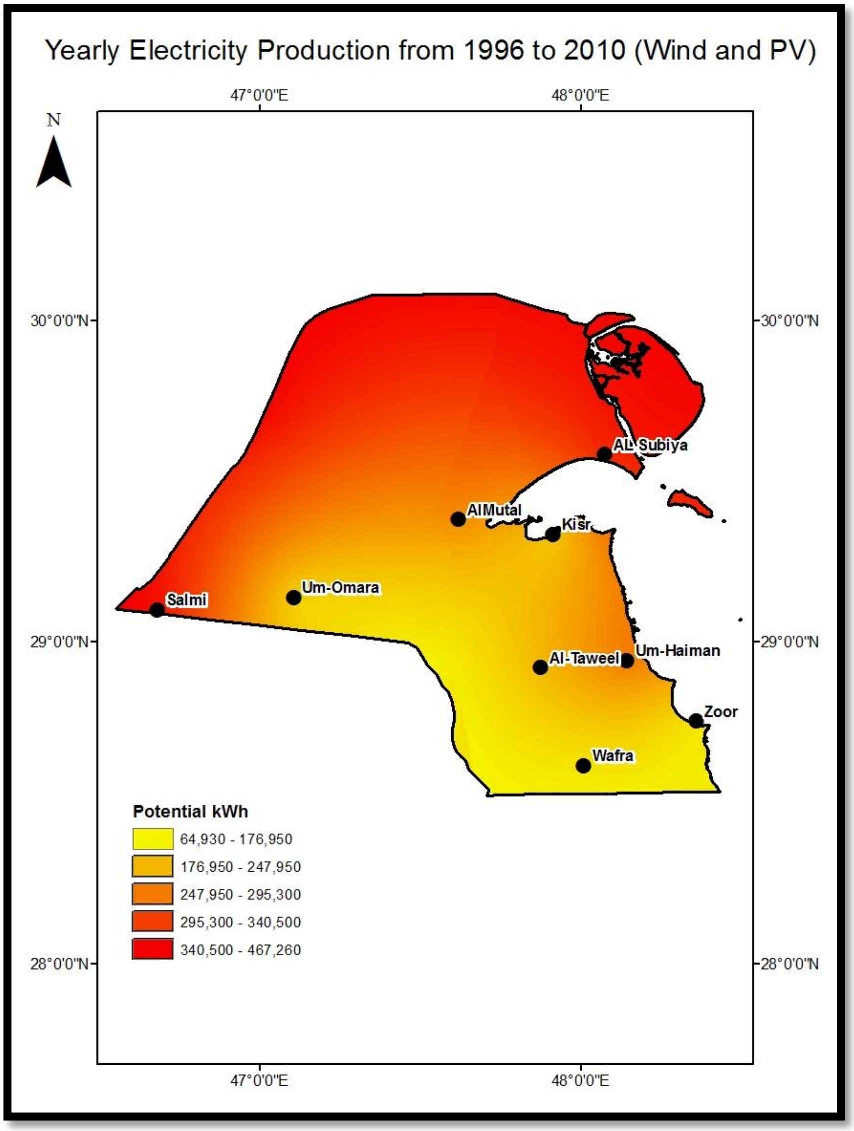


Figure 44 Potential kWh productions by using hybrid system (GE wind turbine and PV)

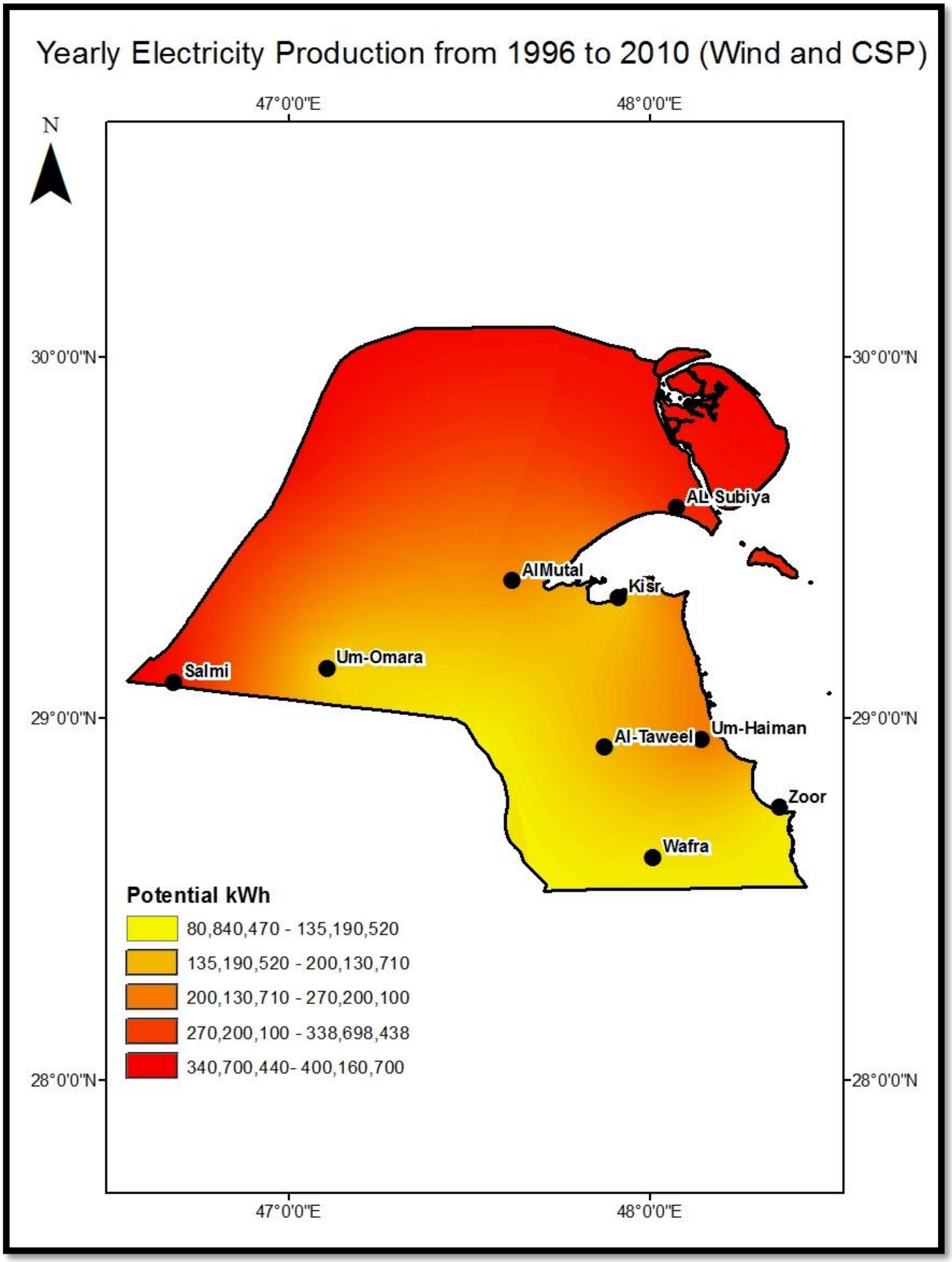


Figure 45 Potential kWh productions by using hybrid system (GE wind turbine and CSP)

Hybrid System Optimal Locations

Salmi and Subiya are the best locations for Solar (PV/CSP) farms and wind farms, and both will be the optimal locations to utilize hybrid systems to produce electricity to meet the high demand, especially with urban expansion and development. The following figures demonstrate the optimal location for an hybrid system to generate electricity (Figure 46)

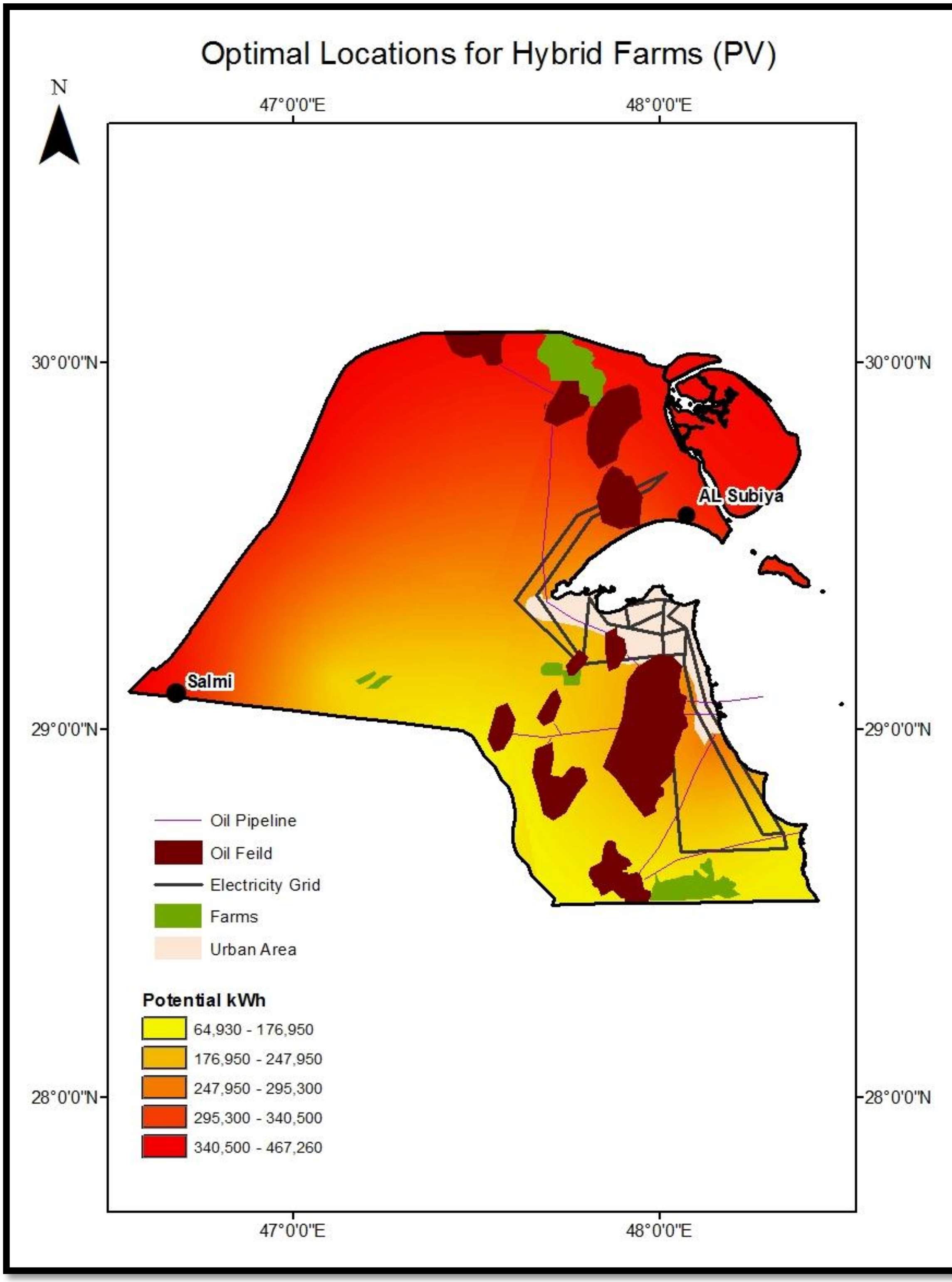


Figure 46 Optimal Location for Hybrid system by using PV

This analysis illustrates that there is a potential for the successful use of solar energy in Kuwait, and that the results of solar and hybrid farm locations and development will be beneficial for future generations of the nation. The areas of Salmi and Subiya are locations where the utilization of both solar and hybrid holds great promise, thus offering opportunities for superior projects for power generation.

Chapter 4

Kuwait Renewable Energy Tool (KRET)

Introduction

Spatial mapping plays a critical role in the siting of renewable energy projects. Governmental, non-governmental, and commercial agencies routinely publish data sets describing the theoretical, technological, and economic potential of different renewable energies in specific locations throughout the world. Spatial analysis allows policymakers, utilities, and planning commissions to directly compare these and other variables and to decide which locations make the most sense for renewable energy development (Alabi, 2012). Spatial analysis is often used as a tool to reduce the social and environmental impact of renewable energy projects. By allowing spatial variables to be displayed beyond those that simply affect energy output, maps and spatial tools enable project planners to avoid major project complications.

Spatial tool examples

Web-based solar (PV) mapping products are increasing in prevalence (Dean et al, 2009). Web-based solar PV mapping tools contain three levels of input data that are used to approximate the performance of a PV array at a given location. The first level is topographical data associated with a given location. Certain of the maps use DEMs to examine the impacts of shading obstructions, identify roof tilt, and approximate the quantity of roof area that can be used for a particular installation. The user is then accountable for defining roof area, tilt, azimuth angle, and a suitable factor to account for the impacts of any shading obstructions (Dean et al, 2009).

The second layer contains the meteorological data that are used to approximate the solar resource at a given site. The third layer consists of the financial and incentive data that is used to calculate the economics associated with a given installation. Some tools have predefined financial and incentive data built into the model, some of which cannot be changed (Dean et al, 2009).

The three layers of input data are then processed to provide an estimate of system size, electricity production, installed cost, and various levels of financial and environmental data. Some of the solar maps have additional features that serve as an all-encompassing source of renewable energy information for consumers in a given city (Dean et al, 2009).

In My Backyard (IMBY) is anther tool with a web-based solar simulation tool, and it is meant to introduce homeowners to the possible benefits of renewable energy. The main purpose of IMBY is to provide an easy-to-use interface to estimate the hour-by-hour amount of electricity produced. IMBY provides a map-based interface and allows a user to specify an address at which to place a PV system (Figure 47; Dean et al, 2009).

Figure 47. The user interface for IMBY (Dean, et al. 2009).

Finally, the user can select an example load profile that aims to represent a household's hourly electricity use. The user can select one from a pre-generated list of cities or upload a personal profile that is used to calculate the amount of energy that the PV system might feed back onto the grid. IMBY uses a local utility's residential purchase rate to determine the user's monthly electricity costs and shaves the cost based on the amount of electricity that is fed back onto the grid (Dean et al,. 2009).

The National Renewable Energy Laboratory (NREL) has launched an interactive online tool to track and share information about photovoltaic solar installations in the United States. The Open PV Mapping Project allows for basic analysis of trends in the US PV market, and as it grows larger in size, will provide opportunities for deeper analysis of the spread of photovoltaic throughout the US (Figure 48). States with PV incentive programs, large utilities and other organizations provided data to seed Open PV before its launch.

NREL hopes that the database will become more robust through the involvement of the PV community (National Renewable Energy Laboratory, 2012).

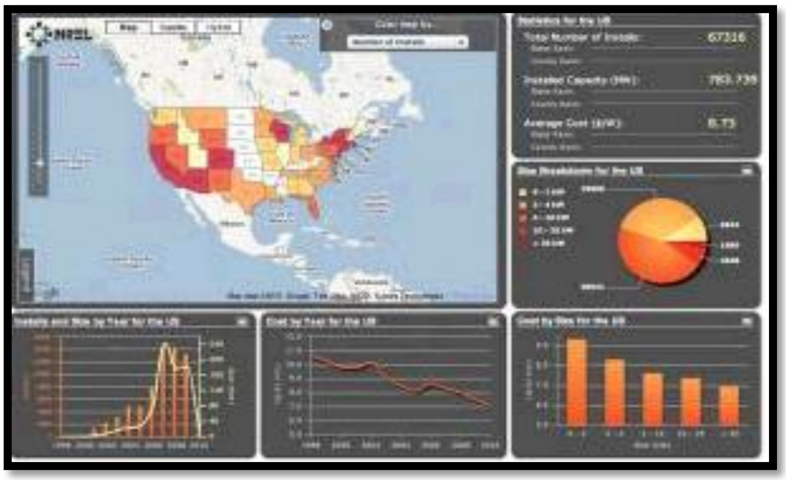


Figure 48. The Open PV Mapping Project (National Renewable Energy Laboratory 2012).

Open PV is currently tracking over 67,000 PV installations producing about 790 megawatts of electricity at an average cost of just over $8 per watt. The database is capable of storing a vast array of data associated with PV installations, which will allow for in-depth analysis, for example by location or over time, as more data is added by users. This will allow counties and even zip code areas within states to compare PV statistics and track the progress of PV growth (National Renewable Energy Laboratory, 2012).

The Kuwait Renewable Energy tool follows these efforts and quantifies the potential for solar and wind at any location in Kuwait to educate the user about the benefits of solar and wind. This chapter details the information that is used in solar and wind mapping. The Kuwait Renewable Energy tool visually represents a specific site and calculates solar and wind system size and projected electricity production. This tool is different from other tools, since it will be the first tool in Kuwait which will provide the opportunity to apply techniques that can allow exploring the renewable energy potential in Kuwait (Figure 50). Also, a wind and solar potential zone map will help in making the decision of where to build wind and solar farm. The Kuwait Renewable Energy tool will support decision and policy makers, planners and researchers in Kuwait with the needed wind energy information. Hopefully KRET will raise awareness as a free tool to help empower cleaner energy decisions for both general public/students/academics/ policy makers.

Objectives

- This tool will help the user to analyze the wind/solar data over Kuwait.
- This tool will act as a network for wind and solar energy information in Kuwait
- This tool will support decision and policy makers, planners and researchers in Kuwait with the needed wind energy information.
- KRET is able to perform “what if ” scenarios for decision makers in Kuwait, “what if” scenarios can be used either to evaluate the effect of different development and planning policies, to select those most suitable or to find the optimum wind farm site among a number of potential sites.
- KRET has the ability to use modeling impacts for the suitable sites and suggest any modifications needed.

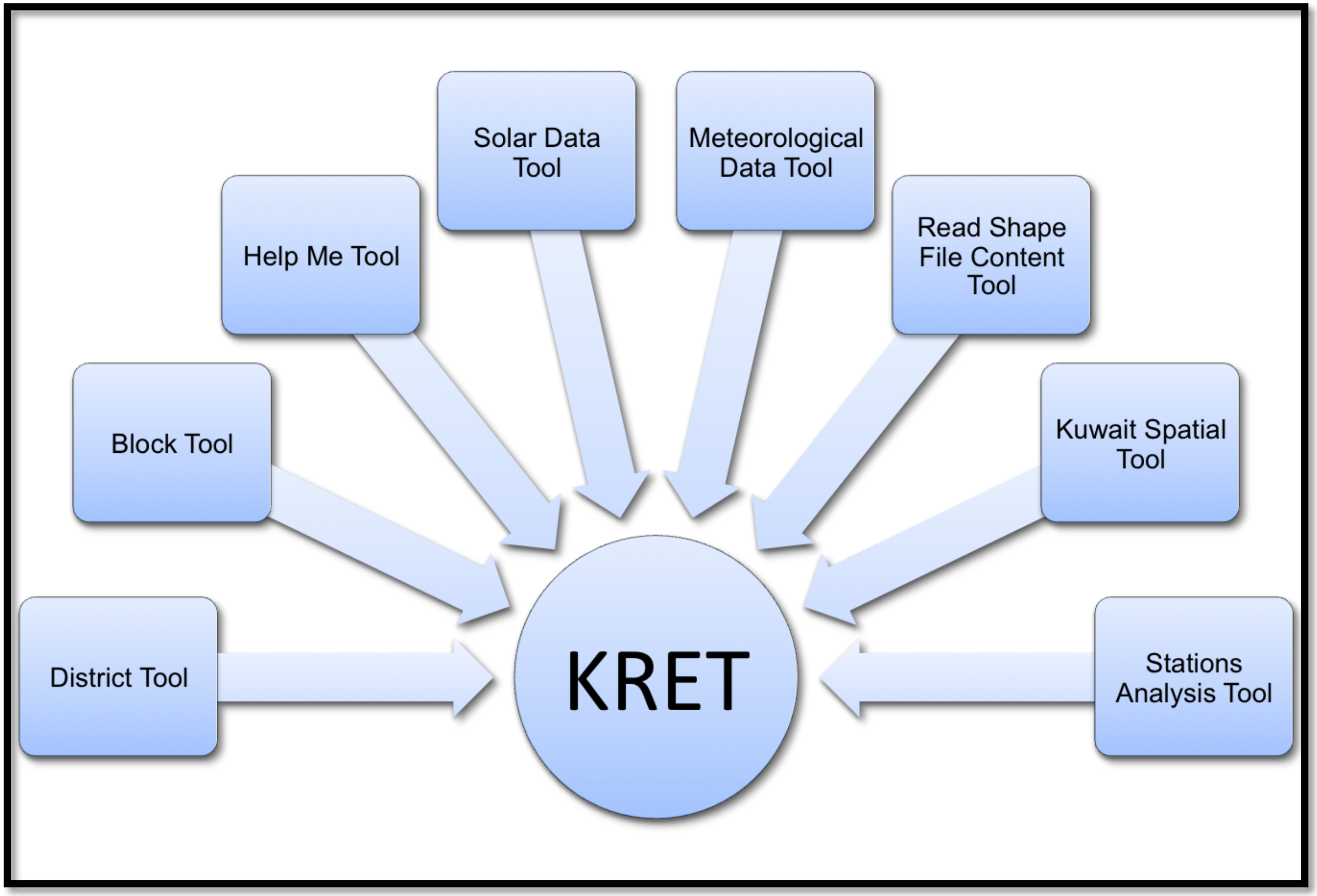


Figure 49. Kuwait Renewable Energy Tool diagram

Methodology

The Kuwait Renewable Energy Tool is a user-friendly ArcGIS toolkit for analysis. This tool provides the user the capability to display, search and analyze and present spatial and renewable energy databases. Interfaces were built to provide the user with such capabilities. The Kuwait Renewable Energy Tool has some similarities and differences with the IMPY and Open PV Mapping Project:

Similarities

- All tools quantify the potential for solar PV at a specific location to educate the user about the benefits of solar PV.

Differences

- Kuwait Renewable Energy Tool analyzes both wind and solar potential
- IMPY and Open PV Mapping Project are web based tools.
- IMPY and Open PV Mapping Project both provide analysis of the US PV market.
-

The followings are descriptions of different tools outputs of the interfaces that compose the Kuwait Renewable Energy Tool:

- Districts
  - Displays the distract names and locations.
- Blocks
  - Displays the blocks, names and locations.

- Kuwait Spatial Tool Kit
    - The user can view wind data and overlay roads, transmission lines, land use and elevation, oil fields, etc.
- Connect to Google Earth
    - Displays and maps selected locations.
- Interpolation and optimal locations
    - Kuwait Wind Density
        - This is an interactive tool that allows users to analyze wind and solar resource data for Kuwait.
    - Kuwait Yearly kWh Map
        - This tool displays the results of the potential of Kwh production in Kuwait from 1996-2010
    - Kuwait Yearly Solar Radiation Map
        - This tool displays the results of the solar radiation
- Help tool
    - This tool helps the user understand the information/ process and the equations behind each tool
- Stations Analysis Tools
    - This tool helps the user to browse over all the nine stations
    - This tool contains the following for each station:
        - Meteorological Data
            - Displays the hourly reading of wind at 10 m/s data from 1996 to 2010.
        - Solar Data
            - Displays the hourly reading of solar radiation from 1996 to 2010.
        - Wind Calculator
            - Displays the 80m wind data analysis.
        - Solar/Wind kWh Data
            - Displays the amount of the kWh potential production for either solar or wind.

Results

The following Figures will demonstrate the results of KRET

Connect to Google Earth Tool

This tool (Figure 50) will display the Kuwait map and any location that the user selects.

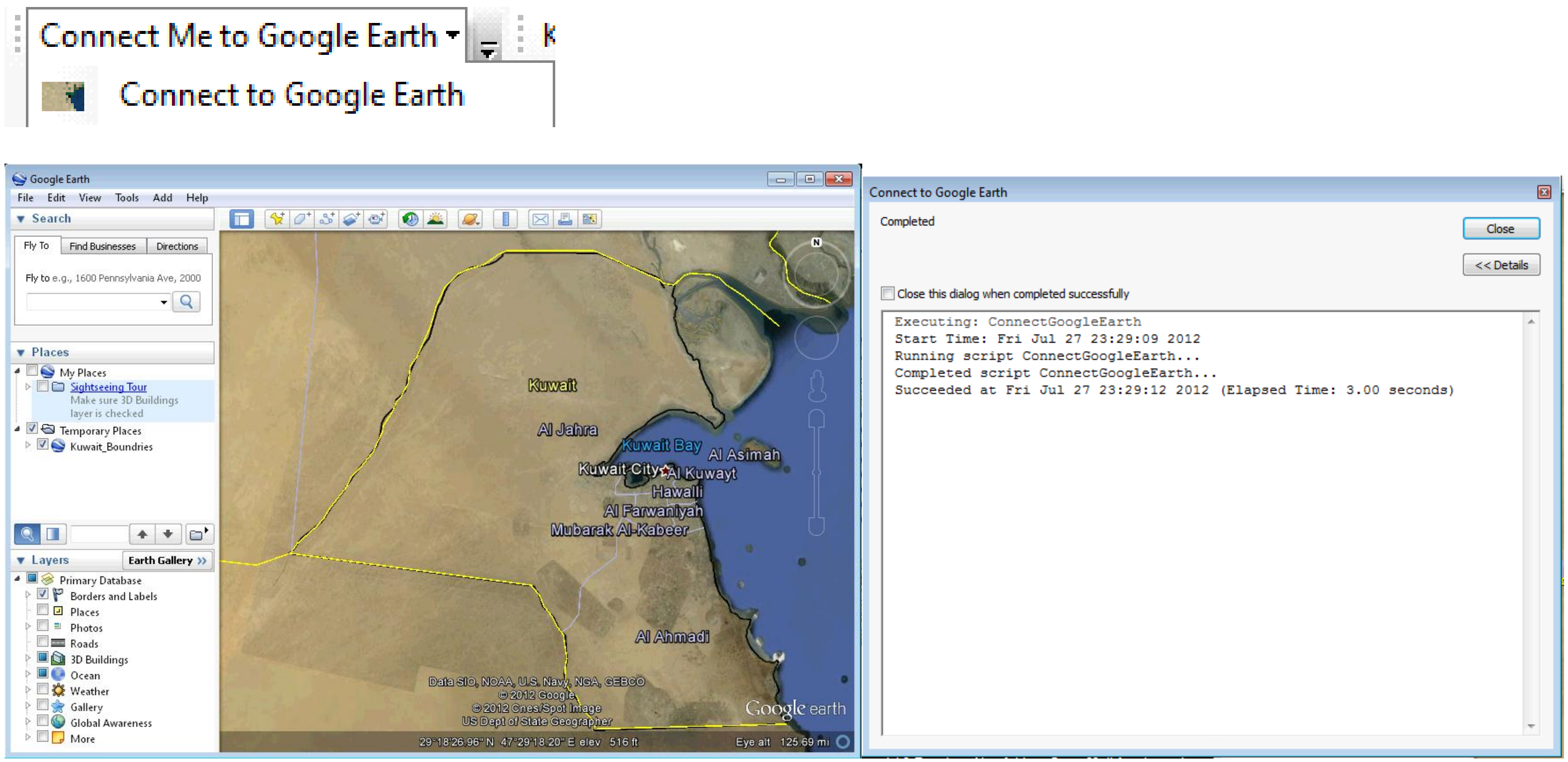


Figure 50 Connect to Google Earth

Interpolation and optimal locations

Kuwait Wind Density

The map will help to select the best location to build wind farms, by selecting locations with 300 or greater in WPD. This tool represents wind conditions in all part of the country at 80 meters. This tool might be helpful to interested wind farm developers who could use this to site stations to obtain an estimate of potential wind energy production.

Kuwait Yearly kWh Map

The solar radiation map shows solar energy potential of an area and provides information that is useful for optimal site selection of a solar energy system and other renewable energy system potentials.

Kuwait Spatial ToolKit Tool

- This geo database contains almost all the spatial variables in Kuwait such as: land use; Farms; Oil Fields; Meteorological Stations etc.
- The Spatial geo database tool (Figure 51) helps to overlay and demonstrate spatial feature over Kuwait.

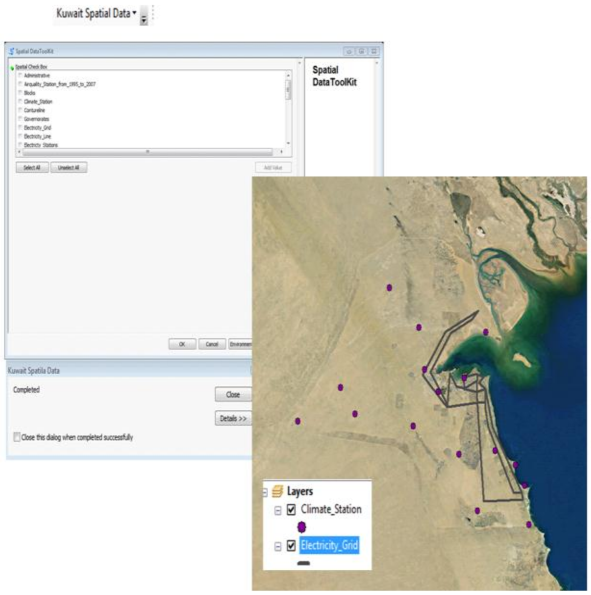


Figure 51 Kuwait Spatial Tool Kit

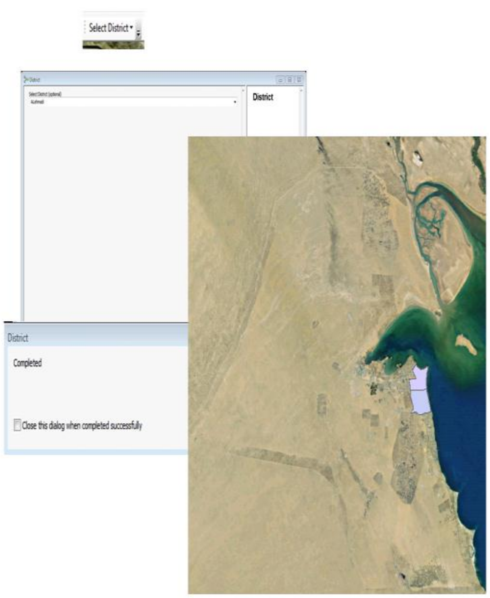


Figure 52 Districts Tool

Districts

Kuwait is divided to approximately five districts, and the purpose of this tool is demonstrate the districts in Kuwait and help to locate and track the best locations for wind farms (Figure 52)

Blocks

This geo database contains all Kuwait residential/commercial blocks, to help users locate and track the best locations install wind turbine/ PV solar for homes.

Help To Understand Tool

This tool will display the answers for the following:

- Who I am (as a tool developer)
- What is Kuwait Renewable Energy Tool (KRET)
- Why using KRET
- Connect me to Google Earth
- Kuwait Spatial Data Base
- Select Districts
- Select Blocks
- Meteorological Data
- Solar Data
- Wind Calculator
- Solar kWh Data
- Wind Monthly kWh

- Wind Yearly kWh
- Solar Yearly kWh
- Interpolation and Optimal Locations (Wind Power Density)
- Solar kWh potential production and Solar Radiation Map

The following is description of station analysis tool (Figure 53) (Um-Omara Station as an example)

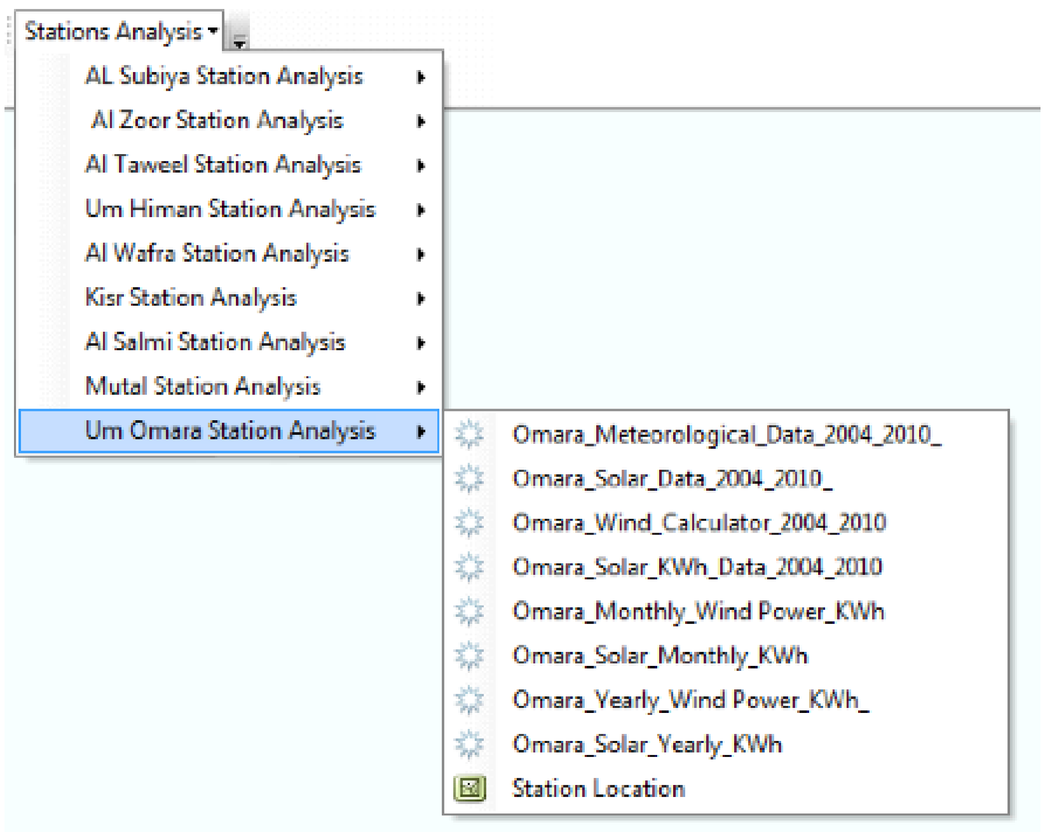


Figure 53 Station Analysis Tool

Meteorological Data Tool

- Demonstrates the raw data for the meteorological stations
- This tool (Figure 54) displays the wind power at 10 m for the following stations Um Omara, Um Himan, Mutla, Zoor, Salmi, Taweel, Wafar and Subiya from 1996-2010.

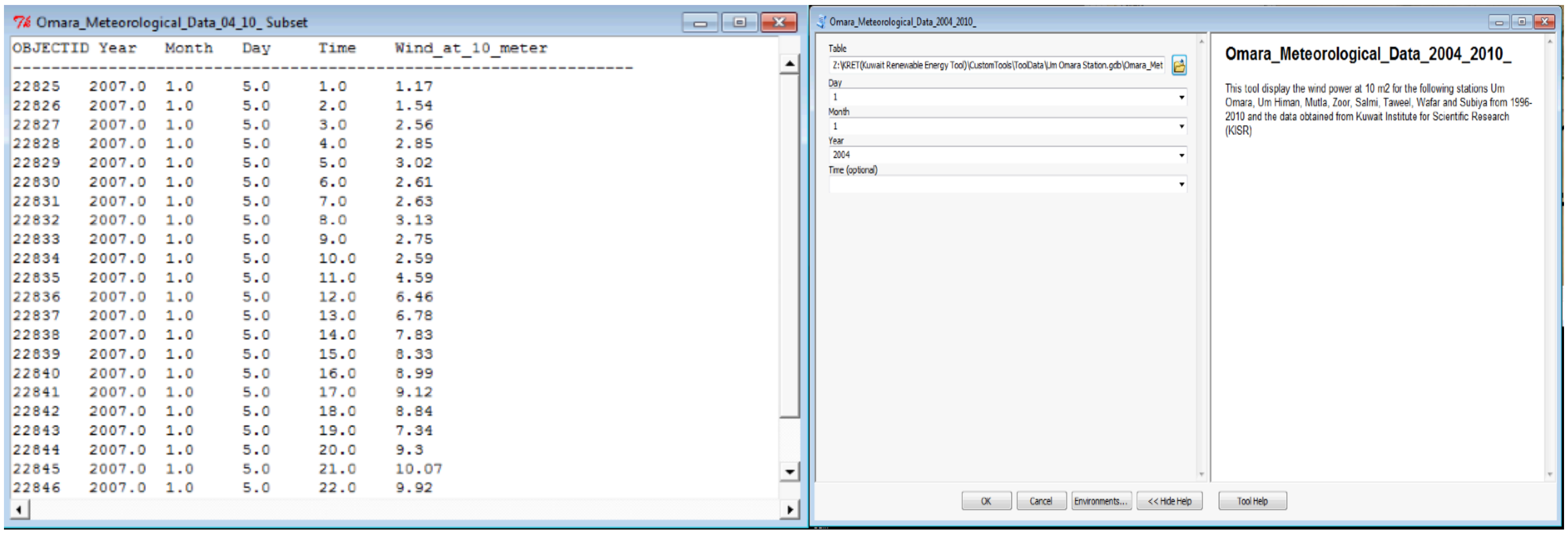


Figure 54 Meteorological Data Tool

Solar Data

- This tool (Figure 55) displays the raw solar radiation data in W/m^2 for the following stations Um Omara, Um Himan, Mutla, Zoor, Salmi, Taweel, Wafar and Subiya from 1996-2010

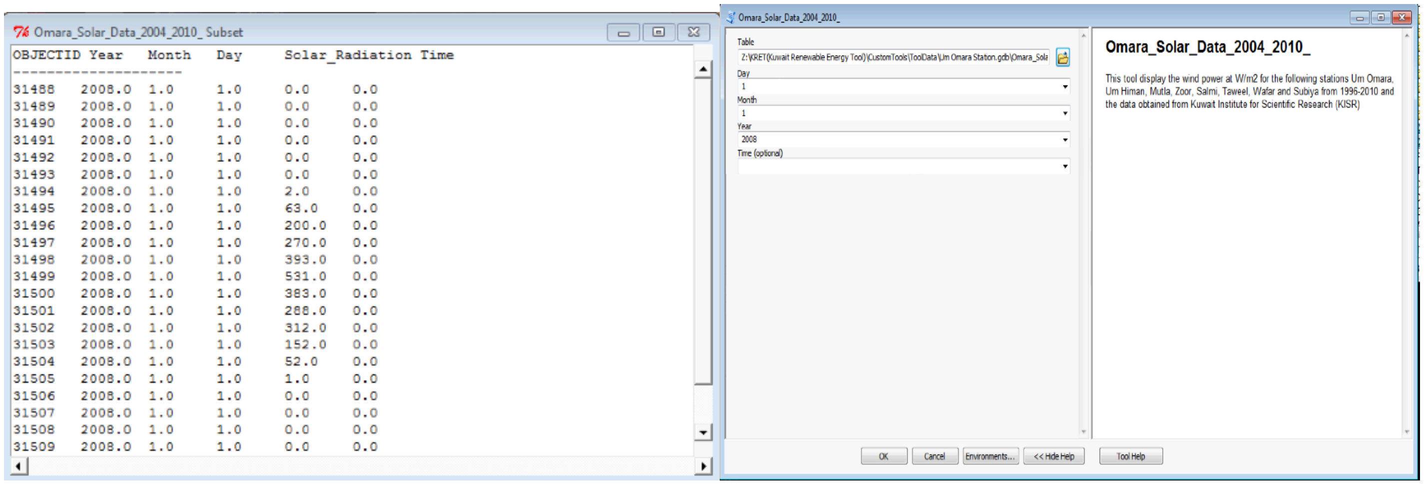


Figure 55
Solar Data

Solar kWh Data

- This tool (Figure 56) displays the hourly potential of kWh from 1996-2010.

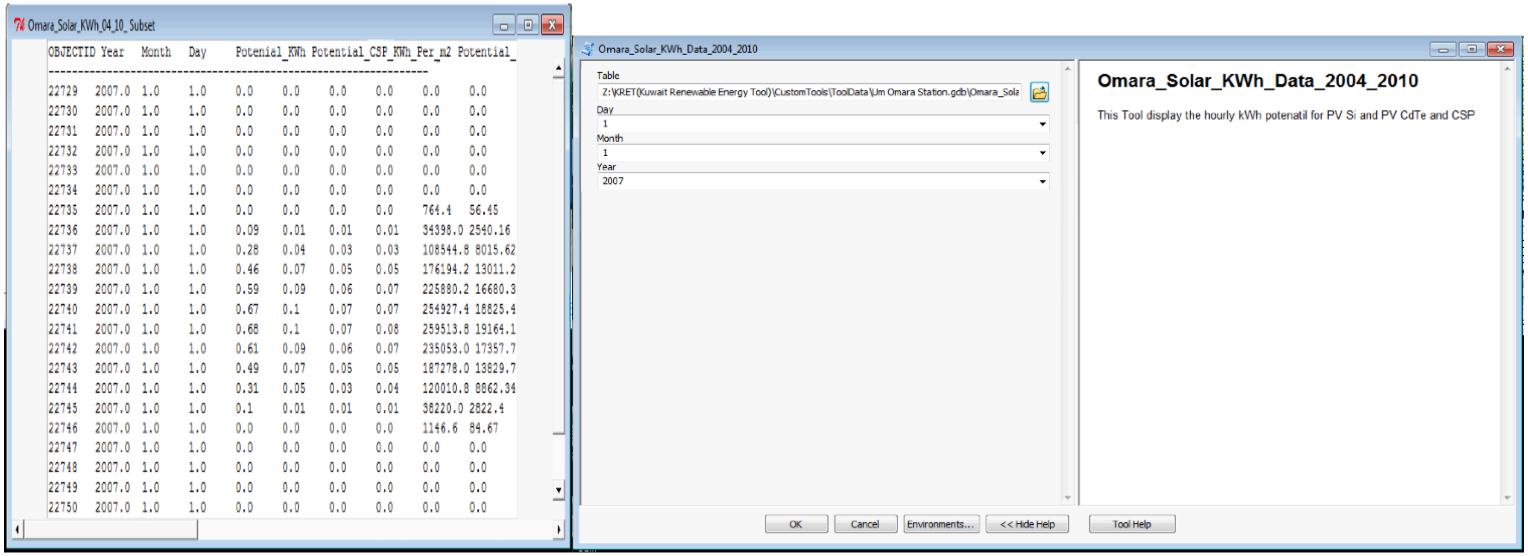


Figure 56 Solar kWh Data Tool

Wind Calculator Tool

This tool (Figure 57) calculates wind power density at 80 meters to evaluate the wind potential at the various stations, and provides data useful for selecting viable locations for situating potential wind farms.

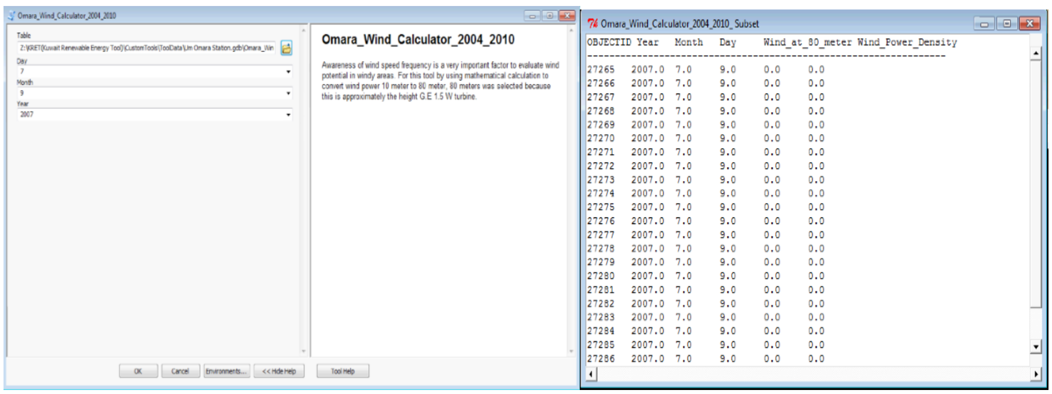


Figure 57 Wind calculator tool

Solar Monthly and yearly kWh

- This tool (Figure 58) will help estimate the monthly and yearly kWh by the following
  - Converting Solar Radiation W/m^2 to kWh, and then calculating kWh per m^2
    - For PV-Si Model, efficiency is 18%, and 2,500,000 m^2 will be considered the total area for this farm
    - For PV- CdTe Model efficiency is 16%, and 2,500,000 m^2 will be considered the total area for this farm
    - For CSP Parabolic Mirrors efficiency is 21%, and 2,500,000 m^2 will be considered the total area for this farm

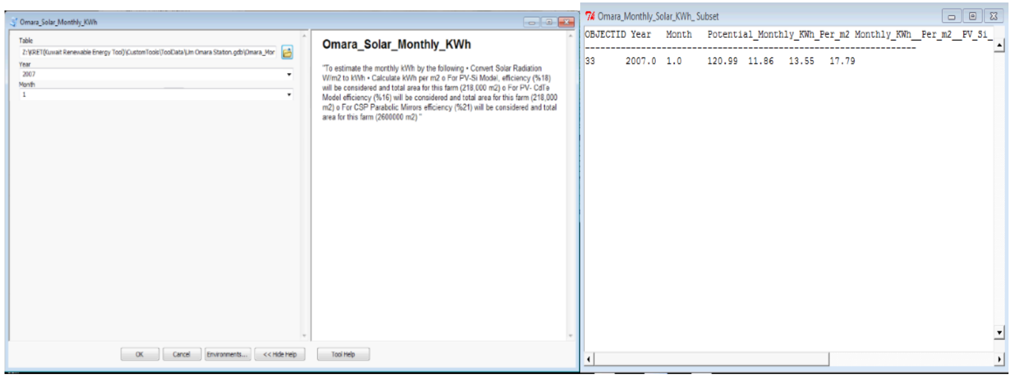
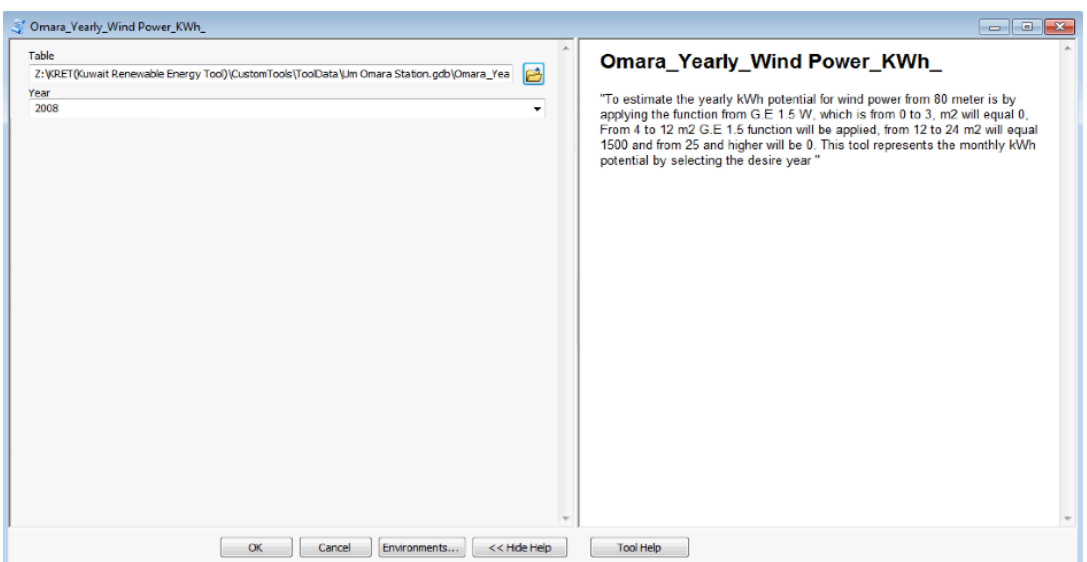


Figure 58 Solar energy tool

Wind Monthly and Yearly kWh

- This tool estimates monthly and yearly kWh potential for wind power from 80 meter by applying the power function for a G.E 1.5 W turbine. This tool (Figure 59) represents the yearly kWh potential.



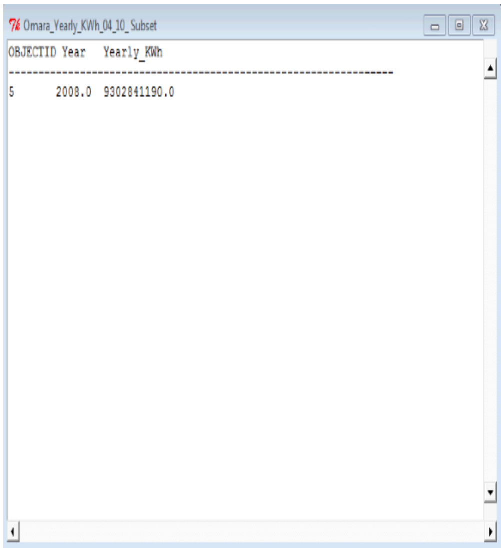


Figure 59 Wind energy tool

KRET tool is first geo-spatial tool in Kuwait to introduce a map-based interface, which is visual and presents spatial and temporal information in a format easily comprehensible to both professionals and non-professional alike. This is particularly significant because in country like Kuwait, the method of disseminating information about renewable energy will greatly influence public acceptance and implementation of wind and solar energy technology. The Kuwaiti consumers are an ethnically diverse group, requiring not only reliable information, but also information that is brightly descriptive and readily understandable in order to make informed and transformative choices about the technologies they use. The Kuwait Renewable Energy Tool (KRET) will be a first science outreach tool that will help to increase public enlightenment and awareness on green energy investments by promoting the use of cleaner and environmental friendly energy supplements.

Chapter 5

Kuwait National Renewable Energy Plan (KNREP)

Introduction

In Kuwait, population and economic growth are the main reasons for the fast increase in energy demand, which leads to two problems: first, Kuwait has one of the highest carbon footprints in the world; and second, the fast depletion of its main energy resource (fossil fuel). This situation highlights the need to establish a renewable energy sector. To address these issues, this chapter reviews the fundamental requirements to introduce relevant renewable energy polices as a first approach to promote renewable energy use in Kuwait.

This chapter first introduces the key features of different renewable energy policy options. Second, it presents a comparative analysis of renewable energy policy mechanisms as well as identifies the requirements for their successful implementation. Third, it describes findings and examples from around the globe and the GCC region, especially the countries that are focusing on renewable energy technologies. Finally, the challenges and existing constraints for the development of renewable energy policy in Kuwait are presented and discussed.

Kuwait's current status regarding its National Renewable Energy Plan (KNREP)

Kuwait's energy sector faces great challenges due to the growing demand in electricity consumption. In order to meet this demand, the electricity and water ministry will need to make substantial investments in order to increase the generation capacity as well as to upgrade and reinforce the distribution and transmission system. Stakeholders in Kuwait can be expected to play a very significant and important role in the energy future of the country and in the process to create the National Renewable Energy Plan. Furthermore, the Kuwait Institute for Scientific Research launched a Renewable Energy Program, which will focus on alternative and renewable energy research in Kuwait. The main aim for this program is to integrate oil, which is the traditional source of energy in Kuwait, with renewable energy sources through diversification, which will help to reduce the local expenditure on consumption by approximately 10% to 20%. In 2012 the Kuwait Institute for Scientific Research adopted a plan in which researchers will implement 29 individual research programs with a new organization that includes research centers as follows (Kuwait Institute for Scientific Research News, 2012).

- Petroleum Research Center
- Water Research Center
- Energy and Building Research Center
- Environment and life Sciences Research Center

The program's goal is to establish three renewable energy plants that will generate electrical energy through renewable energy resources that have been shown to be effective under Kuwait's climatic conditions (Kuwait Institute for Scientific Research News, 2012).

Different policy overview

Despite wide agreement on the need for renewable energy to support the development of a national renewable energy plan, there are several factors that influence the promotion of renewable energy plan development. This section describes a range of policy options, evaluates advantages and disadvantages and makes recommendations for their successful implementation.

Feed-in Tariffs (FITs)

A feed-in tariff (FIT) is an energy-supply policy focused on supporting the development of new renewable power generation. FIT policies may require utilities to purchase either electricity, or electricity and the renewable energy attribute from eligible renewable energy generators. FIT performance-based regulation incentives are meant to increase the adoption of renewable energy sources. Germany applied the Electricity Feed-in Law (1991) to make a more stable market for renewable electricity by offering providers a fixed price for the retrieval of generation costs (Cory et.al., 2009).

Renewable Portfolio Standard (RPS), Renewable Obligation (RO), Mandatory Market Share (MMS) policy or Quotas

With respect to regulations, the government sets the structure within which the market has to produce, sell, or distribute a firm amount of energy from renewable sources. An instrument that is commonly anticipated to advance energy is the quota system, or a Renewable Portfolio Standard. Governments may select to create 'technology bands' in order to defend technologies from competition from lower cost choices. Quotas are typically tradable among companies to avoid market alterations (Cory et.al, 2009). Diverse names are given to a similar set of incentives for renewables in various countries, such as a standard RPS in USA, RO in UK, and MMS in China. The common theme of all these incentives is that the government sets a percentage of electricity to be generated by renewable sources, assigns an actor, such as electricity users, suppliers or generators, to meet the specific percentage and penalizes those who fail to meet their goals. These mechanisms are fundamentally market-founded and they are intended to attain a cost-efficient generation of renewable energy. However, they have not achieved the same success as the FITs in Germany and Denmark (Mezher et al., 2011 a).

Centralized Bidding or Tendering

Centralized bidding or tendering systems these policies generates important competitive pressures for price minimization that will be associated to cost minimization where there is adequate competition, technology learning and manufacturing volume. They are one of the main policies for elevating renewable energy in the electric power sector. These mechanisms have been found to be practical in the early phases of renewable energy growth in UK, and are presently employed for wind power in China below the concession program. The policy mechanism works by calling for bids from investors for renewable energy projects. It is essentially a market-based policy, which intentions to develop renewable energy projects at the minimum possible cost (Mitchell and Conner, 2004).

Tax Credits

One way to lower the costs of renewable energy is through market compensation. The main forms consist of investment, and production tax credits. Tax Credits are largely used in Europe, USA, Japan, and India. Investment tax credits can cover the cost of the renewable energy system itself, or even the entire cost of the installation. Investment tax credits can be valuable at the early phases of the technology development path, where there are high costs, or at times when utilities are deployed on remote areas. They aid in lowering the level of complicated risk and the costs of capitalizing in renewable energy technologies (Sissine, 2006).

Production Tax Credits

The main form of policy support for the U.S. wind industry is the federal production tax credit (PTC), an income tax credit of 1.5 cents/kWh (1992$, adjusted annually for inflation) for the production of electricity from qualified wind plants and other renewable energy facilities. Plants receive the tax credit for the first 10 years of operation, provided they come online by the PTC expiration date. The current value of the PTC is 1.9 cents/kWh. The credit was created under the Energy Policy Act of 1992 and originally expired June 30, 1999. Since then, it has been renewed five times for 1-2 years at a time, currently expiring at the end of 2012 (Barradale, 2010).

Subsidies or rebates

Subsidies are used to share the initial capital cost of the system so that the consumer sees a lower price. Many countries intent on stimulating growth in renewable energy sector have used subsidies. A mixture of investment subsidies, low-interest loans, net metering and public education has resulted in an early success of Photovoltaic in Japan. Similar subsidies have been employed in many countries for renewable energy development. In many cases, they are used in combination with other renewable energy support mechanisms. This is in stark contrast with investment tax credits, which are inclined to favor large companies with greater tax liabilities (Cherni and Kentish, 2007).

Implementation strategy for the National Renewable Energy Plan (KNREP)

Renewable energy policies have been used to expand the share of renewable energy in the power generation sector. FITs, quotas, and bidding policies can be called the major renewable energy promotion policies. Tax incentives and subsides have been helpful in developing markets for renewable energy when applied in conjunction with one of the major policies such as bidding, quotas or FITs. Net metering is another electricity policy, which allows customers of small-scale renewable energy facilities to reduce their electric bill by offsetting their consumption with renewable energy generation relative to consumption (Mezher et al., 2011 a).

The implementation of renewable policies in many countries has resulted in both successes and failures. In the following tables (Table 15 a,b) the requirements for a useful effective implementation are summarized, and advantages and disadvantages of the different policy options are presented.

Table 15 a Advantages and disadvantages of policy types(Mezher et al., 2012).

Type of Renewable Energy Policy	Requirements for successful implementation	Advantages	Disadvantages
Feed In tariffs	-Availability for all potential developers -Guaranteed grid access -Ensure tariffs are high enough to cover for renewable energy generation costs. -Long term contracts for electricity produced. -Set up based on the technology and location	-Most successful at developing renewable markets -Encourage growth of small and medium scale producers. -The stable stream of cash flow reduces the financing risk - Simple implementation -Ensure a stable investment stream for project developers as the profitability of projects if guaranteed.	-Overpriced renewable power due to not adjusted tariffs -Involve restraints on renewable energy trade due to domestic production requirements.
*PPS/MMS/ RO (Quotas)	-Setting a target and adhering to international regulations, such as CO_2 emission control. -Stable political decisions. -Assigning the actors and setting the stage for market to function. -Setting minimum and maximum process for RO Certificates to decrease the damage caused by market instability. -The penalties should be adequately set and strictly enforced -Monitoring and readjustment	-No guaranteed price, which causes consistent pressure for cost reduction. -The policy is market based hence should result in least cost implementation of renewable energy. -Allow trading of renewable energy using green certificated which bring costs down. -Administrative costs are low	-Prices fluctuate a lot, creating instability -High transaction and licensing costs can discourage participation by locals and small investors. -Targets can set upper limits to renewable energy development as the profits drop once the targets reached -Their competitive market based nature concentrates the renewable energy development in resource rich areas. -Complex to design administrate fine tune adjust and areas. -Cost effective technologies (wind) are developed first as compared to costly options (solar photovoltaic)

Table 15 b Advantages and disadvantages of policy types, continued (Mezher et al., 2012).

Type of Renewable Energy Policy	Requirements for successful implementation	Advantages	Disadvantages
Bidding Tendering	-Set up tariff based on the technology and location - Setting the amount of renewable electricity capacity -Developing the infrastructure	-Creates competitiveness among the developers and serves to reduce the cost of renewable electricity. -Different targets for different renewable technologies, this results in incubation of new and costly technologies.	-Drop of prices to unrealistic levels. -In the absence of a strong local manufacturing industry, the pressure to reduce costs, forces the project developers to buy cheaper equipment from foreign manufactures -Problems of continuity and satiability.
Tax Credit	-Bids from project developers with the lowest cost of electricity -Lowering the costs of renewable energy through market compensation, in the form of production tax credits	-Helped in developing a strong service industry. -Lower the level of risk involved and the costs of investing in renewable energy technologies.	-Boom-Bust cycles due to time limitations. -No drive to increase performance
Subsidies/Rebates	-Lowering the installation costs of renewable energy projects	-Low operation and maintenance cost	-Have upfront investment cost -Given for lowering installation costs, hence do not guarantee actual production of renewable energy.
Net Metering	-Easy to install	-Reduce electricity bill. -Don't have to store excess generation in batteries. -No risk of electricity disruption	-Cost of the interconnection -Threat to profitability of utility companies

The need for new strategies

Kuwait's economy is overwhelmingly dominated by oil and natural gas. Kuwait's economic characteristics are fundamentally different from other countries and these differences have an important bearing on economic policy. The magnitude of Kuwait's oil and natural gas wealth, no matter how it is calculated, overwhelms other indicators of economic activity. Also, the size of the wealth remains enormous, irrespective of the form and type of calculation. Under any scenario for the future, Kuwait is placing itself at high risk if it does not confront the need for appropriate wealth diversification, transformation, and management strategies (Choucri and Lynch, 1988).

Thus, a national renewable energy policy is required for Kuwait for the following reasons:

- Renewable energy development will have an impact on future generation and infrastructure investment and planning.
- Renewable energy technologies will support an increase in employment, knowledge, and growth in Kuwait.
- To open new opportunities for investment in renewable energy projects will enable investors to achieve sales contracts.
- Renewable energy will reduce the use of petroleum and it will free resources to be sold in the export market.

Current market development in Kuwait and the Gulf Cooperation Council (GCC) region

The market development of renewable energy in Kuwait and the GCC States has been stifled by a mixture of mostly nontechnical restraints. The restraints that act against renewable energy are mostly the absence of commercial skills and information, the absence of a relevant legal and policy framework, and the high initial capital costs coupled with a lack of fuel-price risk assessment as well as the exclusion of environmental externalities in the cost. Efforts for renewable energy development in the GCC region are related to the three constraint categories of the market technology, policy legislation, and cost (Patlizianas et al, 2006).

- Market technology: A significant market presentation restraint is the non-existence of country assistance market strategies for renewable energy. The absence of dissemination and utilization of scientific knowledge increased in laboratories and interaction with possible users, policy makers, planners and manufacturers is a major constraint in the region. Renewable energy applications do not have the social amenity infrastructure enjoyed by the large towns and cities (Table 16) (Patlizianas et al,. 2006).
- Policy legislation: A shared characteristic for all the GCC States is the absence of well-organized policies and strategies as well as the absence of qualified legal framework/agreements for the promotion of renewable energy. The industry did not start a viable domestic market since the governments in terms of national goals, legislation and partnership agreements with the international industry did not inspire it. The renewable energy market appears to face the opposition of existing interest groups that benefit from the actual dependence on conventional energy sources and try to delay renewable energy development through political means (Table 17; Patlizianas et al, 2006).

- Cost: The obtainability of governmental subsidies for oil and electricity generation and non-availability of similar subsidies for renewable energy activities is a shared constraint of the regional energy system. Such subsidies constrain the chances for renewable energy competing with the commercial energy sources that are available in the region. These countries did not develop these solutions in the region, since heavily subsidized energy tariffs have limited the development opportunities (Table 18; Patlizianas et al, 2006; Page 4).
-

Table 16 Market technology constraints for Kuwait and GCC (Patlizianas et al,. 2006)

Categories	Countries performance		
• Accessibility to credit	*Good* -------	*Fair* Saudi Arabia, United Arab Emirates	*Problems* Bahrain, Kuwait, Oman, Qatar
• Technology performance uncertainty/risk	*High* Bahrain, Kuwait, Oman, Qatar	*Normal* Saudi Arabia, United Arab Emirates	*Low* -------
• Technical skills and information	*Existing* Saudi Arabia, United Arab Emirates	*Lacking* Bahrain, Kuwait, Oman, Qatar	-------
• Commercial skills and information	*Existing* -------	*Lacking* All	-------
• Non-existence of country assistance strategies	*Yes* All	*No* -------	-------
• Awareness/experience in Social, rural, environment sectors	*Good* -------	*Fair* Saudi Arabia, United Arab Emirates, Oman	*Low* Bahrain, Kuwait, Qatar

Table 17 Policy legislation constraints for Kuwait and GCC (Patlizianas et al,. 2006)

Categories	Countries performance		
• Absence of relative legal and policy framework	*Yes* All	*No* -------	-------
• Restrictions on sitting and construction	*Yes* Bahrain, Oman	*No* Kuwait, Qatar Saudi Arabia, United Arab Emirates	-------
• Accessibility to transmission system	*Good* -------	*Fair* Saudi Arabia, United Arab Emirates	*Problems* Bahrain, Kuwait, Oman, Qatar
• Utility interconnection requirements	*High* All	*Normal* -------	*Low* -------
• Liability insurance requirements	*High* All	*Normal* -------	*Low* -------

Table 18 Cost constraints for Kuwait and GCC (Patlizianas et al,. 2006)

Categories	Countries performance		
• Subsidies for competing fuels	*Yes* Kuwait, Oman, Qatar, Saudi Arabia	*No* Bahrain, United Arab Emirates	-------
• Initial capital cost	*High* All	*Normal* -------	*Low* -------
• Difficulty of fuel risk assessment	*Yes* All	*No* -------	-------
• Power pricing assessment	*Favorable* -------	*Unfavorable* All	-------
• Transaction costs	*High* Kuwait, Oman, Qatar, Bahrain	*Normal* Saudi Arabia, United Arab Emirates	*Low* -------
• Exclusion o environmental externalities in the cost	*Yes* All	*No* -------	-------

Comparative policy analysis between countries adopting renewable energy technologies

International examples

When viewed in a qualified international context Kuwait is far behind the world's leaders in renewable energy. The current move to develop a renewable energy sector is an unparalleled initiative in the region that might play a significant part in setting the phase for similar decisions by other comparable countries. What follows is a review of different policies in other countries.

Renewable energy policy in the United Kingdom (UK)

The United Kingdom has one of the world's richest resources of several renewable energies, particularly in wind power and other alternative such as wave power. In spite of the richness of its renewable resources, the UK has frequently lagged behind its actual potential and government targets as shown (Table 19). Figure 60 shows the percentage of electricity obtained from renewable energy sources since the 1990's, and the important policy interventions for supporting renewable energy development (Mictchell and Conner, 2004).

Table 19 Actual and fulfilled percentages of the renewable obligation capacity targets of the UK (Mezher et al., 2011 a).

	2003	2004	2005	2006	2007	2008
Target percentage	3%	4.3%	4.9%	5.5%	6.7%	7.9%
Actual percentage	2.2%	3.1%	4%	4.4%	4.9%	5.4%

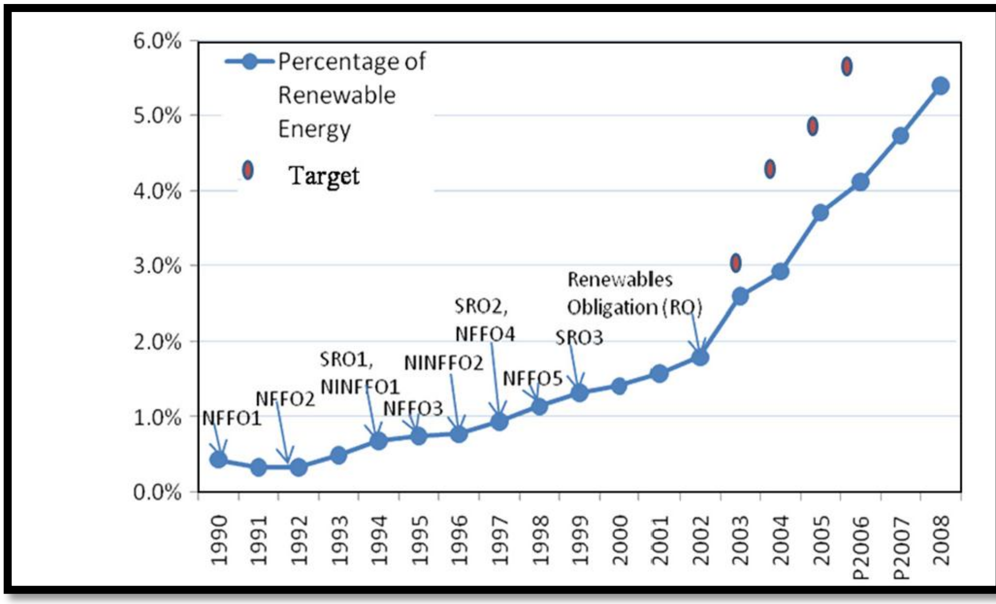


Figure 60. Percentages of electricity obtained from renewable energy in UK (Mezher et al., 2011 a).

The UK experience is that the renewable energy support mechanisms have gone through many alterations. Even in current times, the system is continually developing to accomplish efficient implementation of renewables. The UK over the years has hung on to market-based systems, non-fossil fuel obligations, and renewable obligations and these systems have failed to deliver successful deployment. Currently the new policy includes feed-in-tariffs for small-scale generation. The UK renewable energy history also shows the importance of providing sustenance to costly but promising technologies; this too has been corrected lately by the introduction of renewable responsibility. From the technical side, other barriers to the UK meeting its targets include the problems experienced by renewable generators to access the electric power grid as well as the shortage of the industrial capacity to supply the wanted renewable generation to meet the target (Mictchell and Conner, 2004).

Renewable energy in Germany

Germany is a leading country in the renewable energy sector. Its evolution as a main renewable energy generator and technology leader was brought about by effective renewable energy promotion policies of the country. Figure 61 shows the percentage share of renewable energy sources in Germany through the 1980s to 2008. The rising curve is indicative of Germany's progress in promoting renewable energy (Lipp,2012).

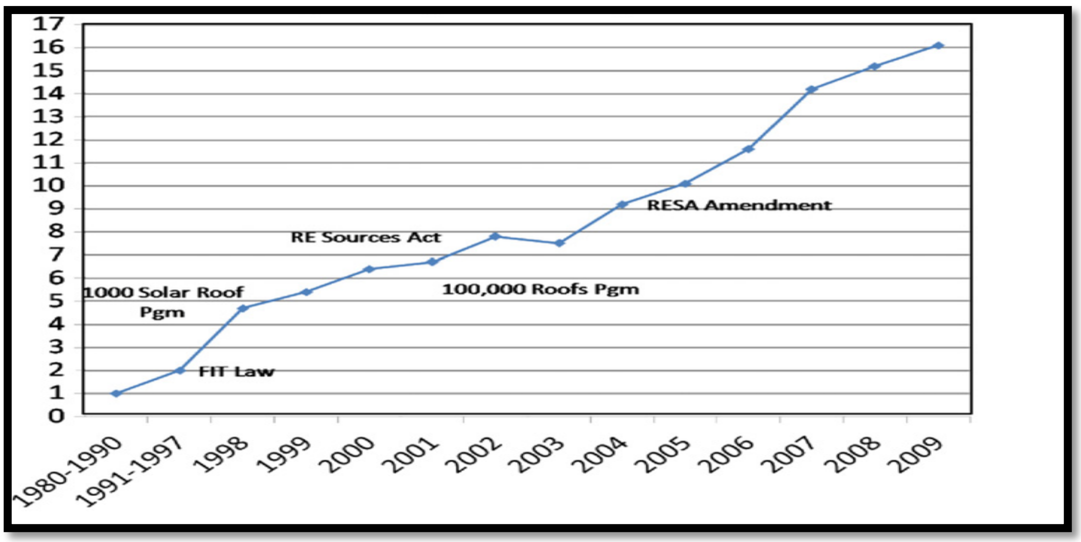


Figure 61. Renewable energy percent share in Germany's electricity generation (Mezher et al., 2011 a).

Germany has had policies in place to support research and growth in renewable energy since 1982. In the mid- 1980s, a series of proposed energy policy reforms were formulated, including the electricity feed in law for generation from renewables. The Red-Green Federal Government program brought in a new energy policy, which highlighted ecological modernization, climate change policy, job creation and socio-economic development. The 2000 Renewable Energy Sources Act and its 2004 alteration were the main feed- in laws of the new energy policy. The Renewable Energy Sources Act on Granting

Priority to Renewable Energy Sources was accepted in April 2000, with an acknowledged purpose of doubling renewable energy sourced electricity production by 2010. This act, which became one of the pivotal acts of the red-green coalition, repealed the Feed-In Law of 1990 but maintained an important feature. Germany witnessed a stable provision from its government in terms of applied renewable energy policies, the support for renewable energy technology progress, and increases in its population awareness, which made Germany a successful example in this sector (Toke, 2008).

The following tables (Table 20a,b, c,d) are selections of countries mainly focusing on renewable energy (RE) technologies. This table covers renewable energy policies *(Feed In tariffs (FIT), Building Integrated Photovoltaic's (BIPV), Printed circuit boards (PCB), Renewable Energy Sources (RES), Renewable Obligation (RO), Non Fossil Fuel Obligation (NFFO), The Green Company (TGC)),* targets, and projects, produced electricity and installed capacities.

Table 20a. Renewable energy sources, policies, targets, and installed capacity summary of 7 countries (Mezher et al., 2011 b).

Country	RE Policy	RE mechanism	RE Target		RE Projects		
			Primary energy	Electricity	Type	Electricity Produced	Installed Capacity
UK	RO since 2002	TGC as part of RO scheme	10.4% by 2010/2011	12% by 2012	Small hydro		0.173 (GW) as of 2008
	Public investment and Loans	R&D and offshore wind support. A total 10.4 billion GBP for low carbon economy.	15.4% by 2015/2016	15% by 2020	Wind	1.30%	4.05 (GW) as of 2009
	Energy Tax	Tax exemption for electricity from RE.			Solar PV		0.032 (GW) as of 2009
	FIT, Quotas and NFFO				Biomass	2.80%	1.368 (GW)
					Hydro power	2.30%	1.513 (GW)

Table 20b. Renewable energy sources, policies, targets, and installed capacity summary of 7 countries, continued (Mezher et al., 2011 b).

Country	RE Policy	RE mechanism	RE Target		RE Projects		
			Primary energy	Electricity	Type	Electricity Produced	Installed Capacity
Germany	FIT since 1990	Investment support for solar PV	18% by 2020	12.5% by 2010	Small hydro		1.4 (GW) as of 2008
	Investment tax credit	Parts of the revenue of energy taxes finance RES			Wind	6.40%	25.78 (GW) as of 2009
	PCB				Solar PV	1%	9.83 (GW) as of 2009
	Net metering				Geothermal		0.006 (GW) as of 2008
	Capital subsidies and grants	Only in exceptional cases 30% of invest.			Biomass	4.40%	4 (GW) as of 2008
	Energy tax	Eco-tax on conventional electricity			Concentrated Solar Power		1.5 (MW) as of 2009
	Public investment and Loans	R&D support			Hydropower	3.30%	4.7 (GW) as of 2008

Table 20c. Renewable energy sources, policies, targets, and installed capacity summary of 7 countries, continued (Mezher et al., 2011 b).

Country	RE Policy	RE mechanism	RE Target		RE Projects		
			Primary energy	Electricity	Type	Electricity Produced	Installed Capacity
China	FIT since 2005		15.4% by 2020	21% by 2020	Small hydro		60 (GW) as of 08
	Public investment	A total of USD731 million is allocated to support biogas			Wind	0.20%	26.01 (GW) as of 2009
	Capital subsidies and grants	A subsidy of (USD2.93)/W to support the BIPV system installation.			Solar PV		0.3 (GW) as of 2009
	Energy tax, Tax credits						
UAE	Quotas, Bidding and Subsidies			7% by 2020	Solar PV		10 (MW)
					Solar thermal		100 (MW)

Table 20d. Renewable energy sources, policies, targets, and installed capacity summary of 7 countries, continued (Mezher et al., 2011 b).

Country	RE Policy	RE mechanism	RE Target		RE Projects		
			Primary energy	Electricity	Type	Electricity Produced	Installed Capacity
USA	RO			20% by 2030	Small hydro		3 (GW) as of 2008
	FIT since 1978				Wind		35.159 (GW) as of 2009
	Energy Tax	Production of Tax Credit-extension			Solar PV		0.824 (GW) as of 2010
	Public investment and Loans	30 billion $ in loan guarantee for RE projects as of 2009			Geothermal	0.40%	3.10 (GW) as of 2009
	Tax credits	Payment in lieu of tax credits for investment on RE			Biomass		8 (GW)
	Capital subsides and grants				Concentrated Solar Power		188 (MW) as of 2009

Regional examples (Gulf Cooperation Council Countries)

United Arab Emirates

The Abu Dhabi government has set a quota system for its renewable energy policy that requires having 7% of electricity generation coming from renewable sources. Solar power is the most promising source of renewable energy for Abu Dhabi. A 10 MW PV solar plant is already installed and operating, and provides power to Masder City operations and is connected to the existing grid. Table 21 a and b demonstrate the potential of renewable energy application in domestic usage, which comprise 44% of the total electricity consumed in Abu Dhabi (Mezher, 2011 b).

Table 21 a. Renewable energy policy potential in Abu Dhabi (Mezher et al.,2012)

Type of Renewable Energy Policy	Requirements for successful implementation	Abu Dhabi	
		Existence	Comments
Feed In tariffs	-Guaranteed grid access	Yes	Masder City 10MW plant already connected to grid
	-Ensure tariffs are high enough to cover for renewable energy generation costs.	No	Need to restructure
	-Long term contracts for electricity produced.	No	———
	-Set up based on the technology and location	Under consideration	Solar (PV,CSP) 10 MW PV already built and CSP nit yet
*PPS/MMS/ RO	-Setting a target and adhering to international regulations, such as CO_2 emission control, stable political decisions.	Yes	Target of 7% by 2030, access the Kyoto protocol and signed the UNFCCC, Masder being a government project.
	-Assigning the actors and setting the stage for market to function.	Yes	Masder
	-Monitoring and readjustment	To be done	Masder
	-Set up tariff based on the technology and location	Under consideration	Solar (PV,CSP) 10 MW PV already built and CSP nit yet
Subsidies/Rebates	-Lowering the installation costs of renewable energy projects	NA	

Table 21 B: Renewable energy policy potential in Abu Dhabi, continued (Mezher et al., 2012).

Type of Renewable Energy Policy	Requirements for successful implementation	Abu Dhabi	
		Existence	Comments
Bidding Tendering	- Setting the amount of renewable electricity capacity on generation that the country wants to have in the national or regional power system -Developing the infrastructure (transportation electricity transmission, developing policy framework and defining zones suited for project implementation) -Abiding process takes places (a call for tenders or bids from project developers bidder with the lowest cost of electricity)	Yes In progress In progress	National renewable energy target is set at 7% by 2020 Masder is working with all stakeholders For Shams 1 CSP Plant and Nour 1 PV Plant
Tax Credit	Lowering the costs of renewable energy through market compensation, in the form of production tax credits	NA	

Saudi Arabia

The Saudi National Energy Efficiency Program is a master plan for energy conversion in the power sector. The planning target is to achieve a 30% decrease in electricity GDP intensity by 2030 compared with the 2005 level and a 50% reduction of peak demand growth rate in 2015 compared with the average in the period 2000-2005. The National Energy Efficiency Program has advanced energy load management programs, energy efficiency standards and labels and building codes. Nonetheless, the influence of the National Energy Efficiency Program is imperfect, and there is still a need to improve the energy efficiency of new residential and commercial buildings as well as improve public awareness through campaigns (Table 22; Bachellerie, 2012).

In 2009 the final proposal for the National Renewable Energy plan for Saudi Arabia was presented in Riyadh. The plan involved exploring and studying the possibility of renewable energy applications, targets with strict deadlines, and economic considerations of a tariff. The plan embraced new electricity tariff rates to achieve less wasteful patterns of consumption. It’s clear that the current low tariff structure is not optimum for population growth and future electricity demand, and it is the biggest barrier to the development of renewable energy policy in Saudi Arabia (Bachellerie, 2012).

Table 22. National conservation policies for Saudi Arabia (Al-Ajlan et al., 2006)

Strategy	Major Policy Measures	Implementing Bodies
Energy efficiency and energy conversion management	Equipment and standards program	Ministry of Commerce
	Establish energy efficient building codes	Standards Organization
	Establish energy efficient appliance standards	Ministry of Water and Electricity
	Promote energy efficient technologies and products	King AbdulAziz city for Science and Technology
	Reduce energy intensive mechanical and electrical devices	Ministry of Planning
	Restrict energy wasting production practices	Ministry of Finance
	Control unit energy consumption and energy supply through quotas	Saudi Electricity Company
	Protect the market from flooding with inefficient appliances	The private sector and Banks
	Promotion of Energy Service Company	Electricity Regulatory Authority
	Promote renewable energy in remote areas	Ministry of Municipalities and Rural Affairs
Load management	Develop time of use tariff	Ministry of Water and Electricity
	Promote thermal energy storage systems	Electricity Regulatory Authority
	Develop pilot load shifting Encourage utilization of renewable energy during peak load time	The private sector
Financial incentives	Provide loans for energy and load management	Ministry of Finance and Banks
	Tax exemptions for energy efficient products	Electricity Regulatory Authority
	Facilitate loads for energy saving products and insulation materials	Saudi Electricity Company and Related ministries
	Provide monetary energy conversation awards to enterprises	General Commission of Investment
Research, development and demonstration	Encourage coordination among the national research	Electricity Regulatory Authority and King AbdulAziz city for Science and Technology
	Support national energy conservation and management center at King AbdulAziz city for Science and Technology	Standards Organization and Ministry of Water and Electricity and Saudi Electricity Company
	National energy conversation	The private sector and Universities and research institutes

Kuwait National Renewable Energy Plan (KNREP)

Current targets

Kuwait appears to be dedicated to change its future energy mixture. In October 2009, Kuwait announced that it aims to produce 5% of its electricity from renewable energy resources by 2020. One of the proposed projections is that the total power generation for the year 2020 will reach 23 GW, and renewable energy installed capacity is supposed to reach 1,150 MW. These types of energy projects require huge investments and a large number of private stakeholders. Legislative, financial, and socio-economic measures will also need to be advised and implemented in order to ensure the wide adoption of renewable technologies (Bachellerie, 2012).

Moreover, Kuwait's Ministry of Electricity and Water and the Kuwait Institute for Scientific Research are planning to develop a 70MW renewable energy complex at Abdeli in the north of the country. The complex will comprise a 10MW photovoltaic solar project, a 10MW wind farm and a 50MW concentrated solar power facility using CSP technology in 10 million square meters. A separate 228MW solar and natural gas hybrid project is planned at Abdali. The $720 million facility will be built by the private sector and will be overseen by Kuwait's Partnerships Technical Bureau. This independent power project will have a solar capacity of about 65MW and about 163MW in gas-fired capacity (Bachellerie, 2012).

The Abdaliya Integrated Solar Combined-Cycle Project was submitted to Partnerships Technical Bureau Higher Committee, and the contract will be signed in the third quarter of 2013. The project will develop the first solar thermal power plant in Kuwait. The whole capacity of the power plant will be 280 MW, with a solar contribution of 60 MW. A further environmental benefit is that annual CO_2 emissions will be 48,000 tons less than that emitted in a conventional plant of comparable capacity. The plant will deliver services more efficiently than that of a conventional combined-cycle power plant with stable continuous power generation (Bachellerie, 2012).

Toward a Comprehensive Renewable Energy Policy for Kuwait.

There are four main policy approaches to incentivizing renewable energy for successful implementation in Kuwait:

1. *Feed-in-tariffs* set a standard price per kWh for qualifying renewables; they are effective at guaranteeing a revenue stream to generators, but if not set at the right price can distort incentives.
2. *Central procurement* involves an agency providing renewable energy contracts through competitive bidding. Such an agency must be strong, but the process can lead to greater control over capacity and timing
3. *Quota systems* determine the quantity of renewable energy to be procured, and allow the market to set the price. They are effective if a trading infrastructure is in place.
4. *Financial incentives and support mechanisms* make use of existing systems and are administratively easy, but are often insufficient.

It is recommended that Kuwait ought to have a mixed policy among Feed-in-Tariffs and quotas. Tariffs on electricity should reflect the true economic cost of electricity and water from fossil fuel production. This must include the cost of negative environmental, and social impacts. It is clear that government subsidies in Kuwait are indirectly encouraging waste (Al-Ajlan et al, 2006). Also, deregulation of the electricity and water sectors will permit more private investments in new infrastructure of technologies plus renewable energy. The regulation of the energy sector in Kuwait is not likely to occur in the short run but this should not stand as a barrier to executing a FIT policy to encourage small scale renewable energy producers to enter into the market with assurance of a good margin on their interments (Al-Ajlan et al, 2006).

Kuwait's renewable energy policy is at an early stage of development. It currently has no policy framework, renewable energy legislation or regulatory framework in place. KNREP's role would include acting as the authority to draft and implement regulations relating to renewable energy and to assist in the development of a regulatory framework for renewables. KNREP's framework is expected to include feed-in tariffs, which will set the standard price of a kilowatt for qualifying renewable energy generators. The framework may also involve a central procurement agency that awards renewable energy contracts through competitive bidding and regulation of the sector. Also, a regulation will be needed that commits power suppliers to use renewable energy for peak loads.

The expectation is that publication of a KNREP framework will help clarify policy. There has been considerable confusion in the past over who is in charge of what area of the renewable sector and there needs to be clear guidelines over their responsibilities. KNREP is also charged with encouraging the private sector to generate electricity from renewable energy sources. This indicates that developers on a build-own-operate basis will implement renewable energy projects.

It is important to realize that future electrical energy will be insufficient to meet the needs of economic development in Kuwait unless end-use energy efficiencies are significantly improved. Renewable energy policies should take the highest priority, and short-term plan implementation should be immediate. The Council of Ministers (the highest authoritative body in Kuwait) could approve policies and legislation relating to the national economy. Unless the council approves renewable energy policies, they will not be enforceable outside the proposing organization’s sphere of influence, and will be ineffective at a national level. For this reason, it is proposed that a KNREP be formed at the highest level. This will ensure that polices and legislations become mandatory, and are followed by the related ministries and agencies.

Kuwait’s experiences show that integration of renewable electricity onto national grid faces barriers, mainly in the form of incompatible regulations designed for fossil energy. Regulations must be forgiving toward intermittent and somewhat unpredictable generation to prevent renewables from being handicapped by competition with hydrocarbons. To make these changes, Kuwait needs a coordinating body, written policy direction, and changes to utility law.

Policy recommendations

- KNREP office could exist as a sub-ministry at the Kuwait. The new office should be headed by a Kuwaiti leader in the sector and mandated to take steps to meet the goals of Kuwait.

- Kuwait's utility laws should be updated to accommodate renewable energy.
- Establish portfolio standards requiring the Ministry of Electricity and Water, with some flexibility, to prioritize purchases from renewable sources ahead. This is similar preparation to feed-in tariffs, allowing Ministry of Electricity and Water to pay premium prices for solar electricity as well as that produced by Kuwait's future hydrogen developments.
- Amend the Transmission Code to give renewable priority access to the grid.
- A premium payment (feed-in tariff) could encourage investment for small-scale PV installations.

Any national renewable energy plan will have both strengths and weaknesses. The strengths include: the ability to provide financial support; qualified researchers and experts with high motivation to form an active research core; the ability to own some energy technologies; encouraging local and foreign investments; the ability to produce energy technologies at minimum cost through governmental support and enormous increase in electricity demand. On the other hand, the weaknesses could be lack of team spirit and teamwork among some stakeholders, lack of proper incentives, current governmental bureaucratic regulations and rules, insufficient information and information technology infrastructure, and difficulties of transferring some energy technologies.

To advance the national renewable energy plan in the right direction, a communications management plan will be very necessary because it would provide appropriate information and improve the communications level through the Kuwait research community and individual participants. To achieve the purpose of the communications management plan in accordance with the recommendations above, there should be a public website with information on program goals, accomplishments, funding opportunities, and other news. Also, the program should sponsor workshops, conferences, and professional society activities to expand communication and networking throughout the community. Grants for proposals for university centers, and pilot application development programs should be announced to the public and the immediate need for presentations on the program should be made at national and international conferences.

Chapter 6

Conclusions and Recommendations

Conclusions

This study examined the drivers and requirements for the deployment of solar and wind sources and their possible integration into the electricity generation sector in Kuwait. Renewable energy technologies are still limited in Kuwait because compared to the cost of conventional electricity, the cost of renewable energy based electricity is very high. However, ample availability of the solar and wind energy as clean renewable energy in Kuwait offers the country significant opportunities to become a leader in renewable energy sector. In the competition with subsidized oil and gas energy, the success of renewable energy technologies in Kuwait will be subject to the introduction of supporting policies, including financial incentives, and a regulatory framework to encourage deployment and reduce cost.

The increasing population and the high demand for energy in Kuwait are some reasons why the country should begin to seek out alternative forms of energy. It is important to begin examining long-term wind and solar resources over Kuwait to determine the feasibility of this resource as a potential sustainable and renewable energy source. Solar thermal (CSP) plants are a feasible option, especially in the dessert and in open areas. A grid connected PV system could be beneficial to the national grid system. Moreover, absorption systems for building cooling, especially during peak hours, should be encouraged to reduce the electricity demand in the summer. Some locations in the northern and southern regions of Kuwait have potential as sites for wind turbine installations. Therefore, wind energy can be used to provide power to newly planned cities on the borders.

This research and analysis illustrates that there is a potential for the successful use of solar energy in Kuwait, and that the results of solar farm location and solar energy development will be beneficial for future generations of the nation. The areas of Salmi and Subiya are locations where the utilization of solar holds great promise. These prime locations of the country have potential monthly kWh of from 340,500 to 467,260 by using PV technologies and from 340,700,440 to 400,160,700 kWh by using CSP.

The Kuwait Institute for Scientific Research might co-ordinate with the Ministry of Energy and Ministry of Electricity and Water through an integrated program for design, development and installation of wind power generation systems feeding the national power grid (Maheshawari and Shaban, 2006). It would be advisable for KISR to select a suitable commercial/research institution working for the development of low wind speed turbines. This will ensure the selection of an appropriate system for Kuwait. Patterns for daily and seasonal wind power generation in Kuwait are in line with the national power demand. A projected wind power system in the country is likely to deliver maximum power output during the peak summer afternoon season, thus making wind turbines and farms reliable devices for meeting the country’s peak power demands.

Initiatives to increase awareness regarding renewable energy resources in Kuwait

Several initiatives can be implemented to increase public awareness regarding the availability, utilization, and potential for available renewable energy resources in Kuwait. Initiatives targeted to specific stakeholders in the debate – business and government - must also be identified, developed, and implemented. These initiatives to increase public awareness presented below will at the same time pique the notice of specific vested stakeholders. Awareness by both decision-makers and the general Kuwaiti public regarding the potential of renewable energy resources in Kuwait is important for the eventual full utilization of these various renewable domestic energy resources.

Improved awareness could be accomplished in many ways such as: Implementing demonstration projects for testing the most promising renewable energy technologies for Kuwait; Increasing activities related to renewable energy utilization, and Integrating renewable energy systems in public areas and demonstration sites where the technology can be presented for people to appreciate and understand.

This research provides an overview of available renewable energy resources in Kuwait, and suggests a strategy for the potential use of such available renewable energy resources for electricity production. The research compares estimates of the cost of electricity produced from available renewable energy resources with the present-day cost of actual electricity generated in Kuwait, the cost saving from renewable energy resources can be up to $0.021

per kWh. This research and thesis intend to associate the awareness of renewable energies resources as a serious supplement to the use of conventional energy resources.

For Kuwait the most attractive renewable energy prospect remains solar energy. Due to future climate change projections, wind will be weakened; however, there will be more sushine. The development of renewable energy would produce significant semi-skilled job opportunities. In addition, installation and maintenance and the large-scale growth of wind energy in Kuwait will help reduce carbon emissions in the country.

Recommendations

This research and thesis seek to make use of the available renewable energy resources, particularly solar and wind, to lead future economic development in Kuwait.

On the policy level, the Kuwaiti government is recommended to:

- Develop a national energy strategy, which includes ambitious renewable energy targets. The energy strategy might take into consideration long-term energy security, as well as energy efficiency and climate change impact costs.
- Adopt a strong position against climate change, and play a dynamic role in climate change consultations on regional and international levels.
- Adopt a policy to gradually transfer subsidies from fossil fuel technologies to renewable energy.

- Develop a sustainable transport strategy, which encourages no motorized modes and public transport, as well as, alternative renewable fuels.

On the administrative level, the government is recommended to:

- Create a renewable energy and energy efficiency and conservation department in the Ministry of Energy and Ministry of Electricity and Water.
- Increase and facilitate cooperation and communication between the different public authorities and institutes related to the energy and climate change sectors

On the research and information level, energy related government authorities, universities and other scientific and research institutes are recommended to:

- Establish and regularly update a national energy database including information on renewable energy and energy efficiency potential.
- Establish and regularly update a national climate change database, which includes all research and scientific studies related to climate change.
- Increase national, regional and international networking and information exchange on energy and climate change issues to enhance local expertise and knowledge.

Outreach

As lack of awareness has been identified as one of the main barriers to the development of renewable energy, the following recommendations are suggested:

- The establishment of independent institutions, which aim to promote renewable energies for sustainable development, as well as energy efficiency in public and private institutes.
- The adoption of educational programs that promote energy use awareness and sustainable development through incorporating such programs in schools and other educational institutes.

Future Directions For Educational Development Strategies

Education and training can create awareness of the issues and equip people with the technical, ecological and economic knowledge required to implement renewable energy. Education is an essential foundation for market development of the renewable energy industry (Jennings and Lund, 2001). There is an urgent need to develop suitable educational programs for renewable energy resources in Kuwait, it is essential for the young scholars in Kuwait to learn about energy and energy sources, a changing environment and a sense of interdependence of systems on earth. Thus, it is necessary to introduce renewable energy concept at the very early stages of education.

The content of teaching courses on renewable energy varies with the age of the student from primary to secondary school and to university level. For each level there will be various adequate methods to design the content of the course on renewable energy. In general, the content of the course for primary school; is based on quality demonstration, while for secondary school and for university level, the content of the course is based on concept of analysis where the aims are measurements, calculations, system design and performance analysis. The specific objectives of renewable energy program in Kuwait is to develop an awareness among students about the nature of the present energy situation, to make the students aware of various types of nonrenewable sources of energy, their potential and the existing technologies to harness them, to develop functional values and attitudes un the students towards utilization of energy sources, to make the students understand the consequences of various energy related policy measures, and to enable the students to suggest alternative strategies towards slowing the energy crisis in the future (Acikgoz, 2012) .

Renewable energy education should be included at various levels in schools, colleges, universities and other academic institutions. Short-term courses and mass media can help achieve this goal. Certificate and diploma level courses will be needed to train personnel for fabrication, installation and maintenance of renewable energy systems (Acikgoz, 2012).

Educational development can develop the knowledge and skills needed to support all phases of the Kuwait renewable energy program in a timely manner. In order to achieve the objectives, a plan for educational program could be developed as described below. The education program for the implementation of renewable energy entails the deployment of a multi-pronged training strategy which will include formal education in universities and community colleges; on-the-job training; facility-specific-training provided by reactor vendor organizations; direct participation during project implementation and partnerships with experienced power utility organizations for initial operation of power plants, among others (Hasnian, et al, 1998)

The implementation for the educational program will be through:

- The establishment of renewable energy undergraduate program and upgrading of master degrees in renewable energy in Kuwait University.

The program curriculum could be as follows:

- The provision of scholarships, fellowships in renewable energy fields from Kuwait University and others aboard such as Masdar Institute of Science and Technology (MIST) in Abu Dhabi UAE.
- The establishment of a center of excellence in collaboration with advanced renewable energy countries.
- Collaboration with regional and international agencies in fields related to renewable energy. For example, collaborations as well as funding in renewable energy research are on the rise. The aforementioned Masdar Institute of Science and Technology (MIST) venture is a high-profile example of an ambitious venture enjoying the active involvement the Massachusetts Institute of Technology (MIT). MIT will assist MIST in recruiting faculty and in their training. Research parks and laboratories are also being planned as part of major tie-ups with other leading scientific institutions such as Imperial College, London.

- Postgraduate training in the best international institutes

The most ambitious point in undertaking this study is to initiate discussion toward, and suggesting one potential strategy for, achieving sustainability and fiscal balance in the domestic energy production and use agenda for Kuwait. Both the discussion and this proposed strategy introduce substantial changes in the national economic structure in Kuwait, expand the private sector role in the national economy, and significantly develop the human resources potential of the Kuwaiti population. Kuwait is currently using and dependent upon fossil fuel, relying for domestic energy use mainly upon domestically available natural gas to generate electricity. Kuwait has the potential in some geographic locations for the productive sitting and placement of wind farms that presents ultimately an excellent opportunity for policy makers to initiate utility-scale wind-energy-resource utilization projects.

This research is unique and different from other studies and proposals in Kuwait because it has help to identify the potential role of renewable energy sources in Kuwait, examined the drivers and requirements for the deployment of these energy sources and their possible integration into electricity generation sector to illustrate how solar energy can be a suitable resource for power production in the state; and illustrates how it can also be used to provide electricity to the rural and urban areas of the country.

References

- Acikogz C. (2011). Renewable energy education in Turkey. *Renewable Energy*,36 608-611.
- Adejumobi L., Oyagbinrin S., Akinbro F., and Olajide M (2011). Hybrid Solar and Wind Power: An essential for information communication technology infrastructure and people in rural communities. *IJRRAS* 9(1).
- Al- Ajlan S., Al Ibrahim A., Abdulkhaleq M., and Alghamdi F. (2006).Developing sustainable energy policies for electrical energy conservation in Saudi Arabia. *Energy Policy* 34, 1556–1565.
- *International Journal of Sustainable Enegry29*: 76-86.
- ALabi O. (2012). Using GIS to prospect for renewable energy in Nigeria. *LAMBERT academic publishing.*
- Alathel S. (1993). Solar energy in the Arabian Gulf countries. World Solar Summit.
- Alawaji S. (2001). Evaluation of solar energy research and its application in Saudi Arabia – 20 years of experience. *Renewable and Sustainable Energy Reviews*5: 59-77.
- Al-Badi A., Albadi M., AlLawati A., and Malik A.(2011). Economic perspective of PV electricity in Oman. *Energy*36 : 226-232.
- Al Diwan Al Amiri. (2012). About Kuwait. Retrieved (2012, November, 26) http://www.da.gov.kw/eng/aboutkuwait
- Al-Habsi S. and Al-Suderi I. (1996). The role of renewable energy fro decentralized applications in Sultanate of Oman, Volume II: solar energy. Renewable Energy Resource Assessment in Oman. http://www.rera-oman.info/
- Alhusainan H. (2010). Wind resource analysis for the State of Kuwait. Unpublished master thesis. University of Oklahoma, Norman.
- AL-Naser and AL-Karaghouli A. (2000). Wind availability and it’s power utility for electricity production in Bahrain. *Renewable Energy*21: 247-254.

- AL-Naser and AL-Naser (2009). Solar and wind energy potential in GCC countries and some related projects. *Renewable and Sustainable Energy*1.
- Alnatheer O. (2005). The potential contribution of renewable energy to electricity supply in Saudi Arabia. *Energy Policy*33 : 2298-2312.
- Alnbaa Kuwait Newspaper. 08/01/2012. Retrieved (2012, September, 25) http://www.alanba.com.kw/absolutenmnew/templates/local2010.aspx?articleid=314014&zoneid=14
- Alotaibi S. (2011). Energy consumption in Kuwait: Prospects and future approaches. Energy Policy39 : 637-643.
- Ardani, K., and Margolis, R. (2011). 2010 solar technologies market report.
- Bachellerie I. (2012). Renewable Energy in the GCC Countries. Gulf Research Center.
- Barradale, J. (2008). Impact of policy uncertainty on renewable energy investment: wind power and PTC. Energy and Resources Group University of California at Berkeley.
- Boxwell M. (2012). Solar Electricity Handbook. Greenstream Publishing.
- Boyle G. (2004). Renewable energy power for a sustainable future. Oxford University Press: Oxford University Press in association with The Open University.
- Branker K., Pathak M., Pearce J.(2011). A review of solar photovoltaic levelized cost of electricity. *Renewable and Sustainable Energy Reviews*15: 4470-4482.
- Byrne, J. Kurdgelashvili, L. Mathai, M. Kumar, A. Yu, J. Zhang, X. Tian, J. and Rickerson, W. (2010). World solar energy review: technology, markets and policies. Center for Energy and Environmental Policy, University of Delaware.

- Cherni J., and Kentish J.,(2007). Renewable energy policy and market reforms in China. *Energy Policy* 35:3616-3629.
- Choucri N. and Lynch M. (1988). Energy sector of Kuwait: present structure prospects for future development. Kuwait Institute for Scientific Research
- Cory K., Couture T., and Kreycil C.(2009). Feed in Tariff policy: design, implementation and RPS policy interactions. *National Renewable Energy Laboratory.*
- Comsan M., (2010). Solar energy perspectives in Egypt. Proceedings of *the 4th Environmental Physics Conference, 10-14 March 2010, Hurghada, Egypt*
- Dean J., Kandt A., Burman K., Lisell L., and Helm C.(2009). Analysis of web-based solar photovoltaic mapping tools. *National Renewable Energy Laboratory* (NREL).
- Doukas H., Patlitzianas K., Kagiannas A., and Psarras J. (2006). Renewable energy sources and rationale use of energy development in the countries of GCC: Myth or reality? *Renewable Energy*31: 755-770.
- Elhadidy M. and Shaahis S. (2000). Parametric study of hybrid (wind + solar + diesel) power generating systems. *Renewable Energy*21: 129-139.
- Environmental Power Systems. (2012). Masdar PV Solar Power Plant. Retrieved (2012, July, 23) http://www.enviromena.com/Eng/Uploads/Pages/20120322113131Gotha_PD_2012-LR.pdf
- Fesharaki, V. Dehghani, M. Fesharaki, J and Tavasoli, H. (2011). The effect of temperature on photovoltaic cell efficiency. *Proceedings of the 1st International Conference on Emerging Trends in Energy Conservation – ETEC Tehran, Tehran, Iran, 20-21 November 2011.*

- Gastli A. and Charabi Y. (2010). Solar energy prospect in Al Batinah region in Oman. *Renewable and Sustainable Energies Research Group (RASERG)*
- *Gas*tli A., Yassine C., and Zekri S.(2010). GIS-based assessment of combined CSP electric power and seawater desalination plant for Duqum-Oman. *Renewable and Sustainable Energy Reviews*14: 821-827
- Hasnain S., Alawaji S., and Elani U.(1998). Solar energy education a viable pathway for sustainable development. *Renewable Energy* 14, 387-392.
- Hertog, S and Luciani, G. (2009). *Energy and sustainability policies in the gcc. KuwaitProramme on Development, Goverance and Globlisation in the Gulf States,*
- International Energy Agency. (2010) Technology Roadmap Solar photovoltaic energy. Retrieved (2012, July, 23) (a) http://www.iea.org/papers/2010/pv_roadmap.pdf
- International Energy Agency. (2010) Technology Roadmap Concentrating Solar Power. Retrieved (2012, July, 23) http://www.iea.org/papers/2010/csp_roadmap.pdf (b)
- Islam M., Kubo I., Ohadi M., and Alili A. (2009). Measurement of solar energy radiation in Abu Dhabi, UAE. *Applied Energy*86: 511-515.
- Jennings P. and Lund C. (2001). Renewable energy education for sustainable development. *Renewable Energy* 22: 113-118.
- Katilaine J. (2009). Renewable energy and opportunities in GCC. *Economic Research*. NCB CAPTIAL.
- Korthapalli A. and Greska B. Concentrated solar thermal power. Department of Mechanical Engineering Florida State University.
- Kumetat, D. (2009). Climate change in the Persian Gulf – regional security, sustainability strategies and research needs. *Paper for the Conference: "Climate Change, Social Stress and Violent Conflict"*,

- Kurban M. and Hocaoglu F.O. (2010). Potential analysis of wind energy as a power generation source. *Energy Sources* 5, 19-28.
- Kuwait Government Online.(2011). A look at Kuwait. Retrieved (2012, November, 26) http://www.e.gov.kw/sites/kgoenglish/portal/Pages/Visitors/AboutKuwait
- Kuwait Institute for Scientific Research News. (2012). Clean energy initiation wheel rolls in to Kisr. (2012, September, 20) from http://www.kisr.edu.kw/Default.aspx?nid=312&pageId=13
- Kuwait National Meteorological Network. Kuwait Institute for Scientific Research. Retrieved (2010, April 26) from http://www.kisr.edu.kw/
- Maheshawari G. and Shaban N. (2006). Potential of wind power generation in Kuwait. Technical Report Kuwait Institute for Scientific Research..
- Masder, Media Center. Shams 1 Fact Sheet. Retrieved (2012, July, 23) http://www.masdar.ae/en/Brochures/factsheets.aspx?Type=FS&MenuID=55&CatID=54&SubcatID=73&mnu=SubCat
- Masdar Capital, 2010. Masdar City Partnership Opportunities. [Online] (Updated 20 March 2010).Available at http://www.masdar.ae/en/Menu/index.aspx?MenuID=69&catid=32&mnu=Cat [Accessed 25 August 2012].
- Mason M., Almuhtaseb M., and Alwidyan M. (2009). The Energy Sector in Jordan- Current Trends and the Potential For Renewable Energy. *Renewable Energy in the Middle East*. Springer
- MENAFN - Middle East North Africa Financial Network .Expert calls on Kuwait to use renewable energy resources. *Arab Times* 02/25/2009. Retrieved (2012, May,23). http://www.menafn.com/qn_print.asp?StoryID=1093235630&subl=true
- Meteorological Department, State of Kuwait. (1999). Climate of Kuwait. Retrieved (2012, November, 26) http://www.met.gov.kw/

- Mezher T., Goldsmith D., and Choucri N.(2011). Renewable energy in Abu Dhabi: opportunities and challenges. *American Society of Civil Engineers. (a)*
- Mezher T., Dawelait G., Abbas Z. (2011). Renewable energy policies implementation drivers and barriers for Abu Dhabi. *World Renewable Energy Congress 89-13 May 2011, Linkoping Sweden. (b)*
- Mezher T., Dawelbait G., and Abbas Z.(2012). Renewable energy policy options for Abu Dhabi: Drivers and barriers. *Energy Policy* 42: 315-328.
- Ministry of Electricity and Water, Kuwait. Electrical Energy 2011, Statistical yearbook. Statistical Department and Information Center, Kuwait.
- Mitchell C., and Connor P.(2004). Renewable energy in the UK 1990-2003. Energy Policy 32:1935-1947.
- Moghbelli H., Vartanian R. “Implementation of the Movable Photovoltaic Array to Increase Output Power of the Solar Cells ”, Proceedings of the International Conference on Renewable Energy for Developing Countries, Apr. 2006, Washington DC, USA.
- Mokri, A. and Emziane, M.(2011). Concentrator photovoltaic technologies and market: a critical review. *World Renewable Energy Congress 2011- Sweden*
- National Renewable Energy Laboratory (NREL). (2012). The open PV project unlocking PV installation data.
- Liu Q. et al. (2009). Solar and wind energy resources and predication. *Journal of Renewable and Sustainable Energy*, 1.
- Lipp J.(2007). Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. *Energy Policy* 35: 5481-5495.
- Patlitzianas K., Doukas H., and Psarras J. (2006). Enhancing renewable energy in the Arab States of the Gulf: constraints and efforts. Energy Policy 34, 3719-3726.

- Qader, M. (2009). Electricity consumption and ghg emissions in gcc countries. *Energies, 2* , 1201-1213.
- Ramadhan M. and Naseeb A. (2011). The cost benefits analysis of implementing photovoltaic solar system in the state of Kuwait. *Renewable Energy*36: 1272-1276.
- Raouf M. (2008). Climate change threats, opportunities, and the GCC Countries. *The Middle East Institute Policy Brief.*
- Reiche D. (2010). Energy policies of Gulf Cooperation Council (GCC) countries—possibilities and limitations of ecological modernization in renter states. *Energy Policy* 38(5): 2395-2403.
- Sen, Z. (2008). *Solar energy fundamentals and modeling techniques atmosphere, environment, climate change and renewable energy*. Springer
- Sissine F.(2006). Renewable Energy Policy: tax credit, budget, and regulatory issues. *CRS Report for Congress.*
- The European Photovoltaic Industry Association. (2011). Solar generation 6.
- Toke D.(2008). The EU renewable directive- What is the fuss about trading?. *Energy Policy* 36:3001-3008.
- Ucar A. and Balo F. (2009). Evaluation of wind energy potential and electricity generation at six locations in Turkey. *Applied Energy* 1864-1872.
- U.S. Marine Corps. (1990). The Persian Gulf Region, A Climatologically Study:
- Wengenmayr, R., and Buhrke, T. (2008). *Renewable energy sustainable energy concepts for the future.* Wiley-Vch.
- Wise R. and Yang Z. (2012). Wind Energy. Renewable Energy Sources and Climate Change Mitigation, Special Report of the Intergovernmental Panel on Climate Change.

- Wohlmuth, W.(2009). Thin film CdTe module manufacturing. CS MANTECH Conference, May 18th-21st, 2009, Tampa, Florida, USA.
- Yang H. and Burnett L. (2003). Weather data and probability analysis of hybrid photovoltaic wind power generation systems in Hong Kong. *Renewable Energy* 28: 1813-1824.
- Zweibel K. (1999). Issues in thin film PV manufacturing cost reduction. *Solar Energy Materials and Solar Cells* 59:1-18